Frontispiece.

VIEW OF THE TEMPLE OF SERAPIS AT PUZZUOLI IN 1836.

See Vol. II. Chap. xxx.

PRINCIPLES OF GEOLOGY

OR THE

MODERN CHANGES OF THE EARTH
AND ITS INHABITANTS

CONSIDERED AS ILLUSTRATIVE OF GEOLOGY

By SIR CHARLES LYELL, Bart. M.A. F.R.S.

'Verè scire est per causas scire'—Bacon

'The stony rocks are not primeval, but the daughters of Time'—Linnæus, *Syst. Nat.* ed. 5, *Stockholm*, 1748, p. 219

'Amid all the revolutions of the globe the economy of Nature has been uniform, and her laws are the only things that have resisted the general movement. The rivers and the rocks, the seas and the continents, have been changed in all their parts; but the laws which direct those changes, and the rules to which they are subject, have remained invariably the same'—Playfair, *Illustrations of the Huttonian Theory*, § 374

TWELFTH EDITION

In Two Volumes—Vol. I.

Illustrated with Maps, Plates, and Woodcuts

LONDON
JOHN MURRAY, ALBEMARLE STREET
1875

PREFACE

TO

THE TWELFTH EDITION.

The Twelfth Edition of the 'Principles of Geology' was being prepared for the press at the time of the Author's death in the early part of this year.

After the complete recasting which the work underwent in preparing the Tenth Edition in 1867, and the corrections and additions made in the succeeding Edition which appeared in 1872, my uncle had found little to alter. The corrections were few and unimportant; most of them merely verbal. In all instances they have been introduced. With these few changes the work remains the same as the Eleventh Edition of 1872.

LEONARD LYELL.

Kinnordy: *October*, 1875.

PREFACE

TO

THE ELEVENTH EDITION.

THERE has been an interval of five years between the last and present edition of this first volume of the 'Principles of Geology.' During this time much discussion has taken place on important theoretical points bearing on meteorology and climate, and much new information obtained by deep-sea dredging in regard to the temperature, and shape, of the bed of the ocean, and its living inhabitants.

In order to avail myself of this newly acquired knowledge, I have found it necessary to recast Chapters X., XI., XII., and XIII., which relate to the geological proofs of former changes of climate, and the paramount importance of the distribution and height of the land over all other causes in bringing about past variations of temperature. At the same time I have endeavoured to render more intelligible some of those astronomical changes which must periodically affect climate, though probably not in so influentia a degree as some have imagined.

In Chapter XX. I have briefly dwelt upon the latest known facts concerning marine currents, especially those in the Straits of Gibraltar, and have considered some theories of oceanic circulation recently propounded to

account for the cold of the abysses of the ocean. With these exceptions, the work has been reprinted mainly as it stood in 1867, with corrections and additions.

The changes made in the tenth edition were so numerous and important that I have thought it best to reprint the Preface to that edition in full, thereby giving the reader the opportunity of knowing what advance has been made in the work since 1853, when the ninth edition appeared. The pages of additions and corrections given in that Preface correspond so nearly to those of the present volume that the passages referred to may be always found by turning a few pages backwards or forwards.

CHARLES LYELL.

73 Harley Street:
January 15, 1872.

PREFACE

TO

THE ELEVENTH EDITION.

As only three years have elapsed since the last edition of this Second Volume of the 'Principles' was published, I have been able to reprint it with less alteration than was required in the First Volume, between which and the preceding edition there had been an interval of five years.

I have followed the rule adopted in my First Volume of reprinting the Preface to the tenth edition, by which the reader will be directed to those numerous and important additions and corrections which I found necessary in consequence of the progress of the science during the fifteen years which separated the ninth and tenth editions. Although the pages after the first two hundred differ slightly in the present edition, they are not so much altered as to render it difficult to refer to them.

I subjoin a list of the most important points on which I have introduced new information in the present edition.

PREFACE

TO

THE TENTH EDITION.

It is now thirteen years and a half since the last or ninth edition of the 'Principles of Geology' appeared; a long interval in the history of the progress of a science, in which so many able investigators and thinkers, in every civilised country of the world, are actively engaged. In re-editing the work, I have found it necessary entirely to re-write some chapters and to recast others, and to modify or omit some passages given in former editions. For the sake of those readers who are already familiar with the 'Principles,' I subjoin a list of the chief additions now made for the first time, pointing out the pages at which corresponding matter occurs in the ninth and tenth editions.

List of the Principal Additions and Corrections in the First Volume of the Tenth Edition of the 'Principles of Geology.'

Ninth Edition	Tenth Edition.	Additions and Corrections.
Page	Page	
	14	The opinion of Anaximander, 'that fish were the parents of mankind,' how far an anticipation of the modern doctrine of development.
	139	An abridged table of fossiliferous strata in their order of superposition, inserted from the 'Elements' for the sake of reference.
130 to 153	136 to 173	The Ninth Chapter, on the progressive development of organic life, has been entirely re-written.

Ninth Edition.	Tenth Edition.	Additions and Corrections.
Page 73 to 91	Page 174 to 211	The Tenth Chapter (corresponding in part with Chapter VI. of the former edition) has also been re-written. It treats of the changes of climate, established on evidence, organic and inorganic, derived from the Tertiary and Post-Tertiary formations.
92 to 113	212 to 232	The Eleventh Chapter is new, treating of the proofs of former vicissitudes in climate, derived from the study of the Secondary and Primary fossiliferous formations.
113 to 130	233 to 267	The Twelfth Chapter, on the geographical causes of former changes in climate, has been re-written. It is illustrated by three new maps.
100 and 126	268 to 304	In the Thirteenth Chapter, to which there are only a few passages corresponding in former editions, I have considered how far former vicissitudes in climate may have been influenced by astronomical changes; such as variations in the excentricity of the earth's orbit, changes in the obliquity of the ecliptic, and different phases of the precession of the equinoxes. Mr. Croll's suggestion as to the probable effects of a large excentricity in producing glacial epochs is fully discussed, and the question is entertained whether geological dates may be obtained, by reference to the combined effect of astronomical and geographical causes.
204	335	The earth-pillars or pyramids of Botzen in the Tyrol and other localities, illustrated by a drawing of Sir John Herschel's, are here introduced, as showing the power of rain as distinct from that of running water. The glacial origin of the formation of which the pillars are made is also pointed out.
223	372	Notice of the theory of regelation of Tyndall and Faraday in explanation of the motion of glaciers.
	376	The glacier-lake of the Alps called 'the Märjelen See,' described and illustrated by two diagrams, and its bearing on the origin of the parallel roads of Glenroy explained.
	393	Live fish rising in the Artesian wells of the Sahara.
237	398	Facts relating to the origin of mineral and thermal waters and the hot springs of Bath.
	420	Playfair on the origin of the lake-basin of Geneva.
	434	Mr. Horner on the mode of computing the antiquity of the Nile mud; with the opinions of Mr. S. Sharpe, Sir J. Lubbock, and Mr. Wallace on the subject.
	447	A new hypothesis proposed to explain the origin of the 'mud-lumps' of the mouths of the Mississippi, illustrated by a map and two views.
271	457	The antiquity of the delta and alluvial plain of the Mississippi discussed with reference to new facts brought to light during the survey of Messrs. Humphreys and Abbot, in 1861, and the boring of the Artesian well at New Orleans in 1854, to the depth of 600 feet.
	461	Mr. H. W. Bates and Professor Agassiz on the delta of the Amazons.
		Freshwater deposits supposed by Agassiz to indicate an ancient lake closed by a terminal moraine of a glacier considered.
279	475	Delta of the Ganges—Mr. Fergusson's opinion as to the

Ninth Edition.	Tenth Edition.	Additions and Corrections.
Page	Page	
		origin of 'the swatch' and the mode of formation of the elevated banks of rivers.
291	495	Various causes of currents treated of more fully than in the former edition.
306	514	Waste of the coast of Norfolk illustrated by the ruins of Eccles Church as they appeared in 1839 and in 1862. A drawing by the Rev. S. W. King of the church in 1862.
323	539	St. Michael's Mount, Cornwall—Three views of the Mount —Its identity with the Ictis of Diodorus—Drawing of a block of tin dredged up in Falmouth Harbour.
334	563	Temperature of different divisions or basins of the Mediterranean compared to that of the Atlantic—Saltness of the Mediterranean, and a diagram illustrating the result of Captain Spratt's survey.
340	568	Shoals and valleys in the German Ocean—The Silver Pits and Dogger Bank—Comparison of the recent deposits of these shoals and the crag of Norfolk and Suffolk.
	616	Internal talus of Monte Nuovo, containing fragments of marine shells and pottery, with a section of the mountain.
	625	Ropy lava and origin of this structure.
	633	Hypothesis of elevation craters not applicable to Somma or Vesuvius—Ravines on the north side of Somma, and the light which they throw on its structure, from observations made by the author in 1857 and 1858—Presence of land-plants and absence of contemporaneous marine shells in the ancient tuffs of Monte Somma.

The reader may also be interested in knowing the dates of the successive editions of this treatise, as well as of two other of my geological works, which are intimately connected with it.

List of the dates of publication of successive Editions of the 'Principles,' 'Elements,' and the 'Antiquity of Man.'

Principles, vol. i. in 8vo., published in	Jan. 1830.
——— ,, ii. ,, ...	Jan. 1832.
——— ,, i. 2nd edition in 8vo.	1832.
——— ,, ii. 2nd edition ,, ...	Jan. 1833.
——— ,, iii. 1st edition ,, ...	May 1833.
——— New edition (called the 3rd) of the whole work in 4 vols. 12mo.	May 1834.
——— 4th edition, 4 vols. 12mo.	June 1835.
——— 5th ,, ,, ,, ...	Mar. 1837.
Elements, 1st edition in 1 vol.	July 1838.
Principles, 6th ,, 3 vols. 12mo.	June 1840.
Elements, 2nd edition in 2 vols. 12mo.	July 1841.

Principles, 7th edition, in 1 vol. 8vo. published in . . .	Feb. 1847.
——— 8th edition " "	May 1850.
Elements, 3rd edition (or Manual of Elementary Geology) in 1 vol. 8vo.	Jan. 1851.
Elements, 4th edition (or Manual) in 1 vol. 8vo. . . .	Jan. 1852.
Principles, 9th edition, published in 1 vol. 8vo. . . .	June 1853.
Elements, 5th edition, in 1 vol.	1855.
Antiquity of Man, 1st, 2nd, and 3rd editions . .	Feb.—Nov. 1863.
Elements, 6th edition, in 1 vol. 8vo.	Jan. 1865.
Principles, 10th edition, in 2 vols. 8vo., the first now published.	Nov. 1866.

[*** Oct. 1875.—Since the above list was made there were published—

Principles, 10th edition, 2nd vol.	March 1868.
Student's Elements of Geology	Jan. 1871.
Principles, 11th edition	1872.
Antiquity of Man, 4th edition	1873.
Student's Elements, 2nd edition	1874.

L. L.]

The 'Principles of Geology,' in the first five editions, embraced not only a view of the *modern changes* of the earth and its inhabitants, but also some account of those monuments and analogous changes of *ancient* date, both in the organic and inorganic world, which the geologist is called upon to interpret. The subject last mentioned, or geology proper, constituted originally a fourth book, now omitted, the same having been enlarged into a separate treatise, first published in 1838, in one volume 12mo., and called 'The Elements of Geology,' afterwards recast in two volumes 12mo. in 1842, again re-edited under the title of 'Manual of Elementary Geology,' in one volume 8vo. in 1851, and lastly under the title of 'Elements of Geology,' in one volume 8vo. in 1865.

The 'Principles' and 'Elements,' thus divided, occupy, with one exception, to which I shall presently allude, very different ground. The 'Principles' treat of such portions of the economy of existing nature, animate and inanimate, as are illustrative of Geology, so as to comprise an investigation of the permanent effects of causes now in action, which may serve as records to after ages of the present condition of the globe and its inhabitants. Such effects are the enduring monuments of the ever-varying state of the physical geo-

graphy of the globe, the lasting signs of its partial destruction and renovation, and the memorials of the equally fluctuating condition of the organic world. They may be regarded, in short, as a symbolical language, in which the earth's autobiography is written.

In the 'Elements of Geology,' on the other hand, I have treated briefly of the component materials of the earth's crust, their arrangement and relative position, and their organic contents, which, when deciphered by aid of the key supplied by the study of the modern changes above alluded to, reveal to us the annals of a grand succession of past events—a series of revolutions which the solid exterior of the globe, and its living inhabitants, have experienced in times almost entirely antecedent to the advent of man.

In thus separating the two works, however, I have retained in the 'Principles' (Book I.) the discussion of some matters which might fairly be regarded as common to both treatises; as, for example, an historical sketch of the early progress of geology, followed by a series of preliminary essays to explain the facts and arguments which lead me to believe that the forces now operating upon and beneath the earth's surface may be the same, both in kind and degree, as those which at remote epochs have worked out geological changes.

If I am asked whether the 'Principles' or the 'Elements' should be studied first, I feel much the same difficulty in answering the question as if a student should enquire whether he ought to take up first a treatise on Chemistry, or one on Natural Philosophy, subjects sufficiently distinct, yet inseparably connected. On the whole, while I have endeavoured to make the two treatises, in their present form, each quite independent of the other, I would recommend the reader to study first the modern changes of the earth and its inhabitants as they are discussed in the present volume, proceeding afterwards to the classification and interpretation of the monuments of more remote ages.

It will be seen in the foregoing list of the dates of publication, that in 1863 I brought out a volume on 'the Antiquity of Man,' or to state the title more fully, 'On the Geological Evidences of the Antiquity of Man, with Remarks on Theories of the Origin of Species by Variation.'

The subject-matter of this work coincided in part with that treated of in the 'Principles' and 'Elements,' namely, the fossil remains of Man and his works; but whereas these topics occupy a few pages only in the 'Elements' and 'Principles,' half a volume is devoted to them in the Antiquity of Man.' In the latter treatise also, the account given of the Glacial Period, and its relation to the earliest signs of Man's appearance in Europe and North America, is much more expanded than in the 'Elements' and 'Principles,' and regarded from a different point of view. The manner also in which the origin of species is handled in the 'Antiquity of Man' will be found to be different in many respects from that in which I shall view the same subject in the concluding volume of this work.

CHARLES LYELL.

73 Harley Street:
November 6, 1866.

PREFACE

TO

THE TENTH EDITION.

In the Preface to the First Volume I gave a list of the dates of publication of the successive editions of this treatise, as well as of my 'Elements of Geology' and my 'Antiquity of Man,' and pointed out the relation of these two last works to the 'Principles.'

In the same Preface I gave a list of the chief additions then made for the first time; pointing out, so far as was possible, the corresponding pages in the ninth edition; so that readers already familiar with the earlier editions might be able at once to refer to what was new.

I now subjoin a similar list of the chief alterations and additions introduced for the first time into this tenth edition.

List of the Principal Additions and Corrections in the Second Volume of the Tenth Edition of the 'Principles of Geology.'

Ninth Edition.	Tenth Edition.	Additions and Corrections.
Page 396 to 424	Page 1 to 47	Considerable additions have been made to this Twenty-sixth Chapter, on the structure of Mount Etna, in consequence of my re-examination in 1857 and 1858 of this volcano, which I had first visited thirty years before, in 1828. The theory of a double axis of eruption is explained (p. 9), and the changes in the scenery of the Val del Bove, caused by the lavas of 1852, are described (p. 31). The solid texture and steep original inclination of certain lavas of known date are pointed out (pp. 35 & 36). The relation of some ancient valleys on Etna to the former structure of the mountain is considered (p. 40).

Ninth Edition.	Tenth Edition.	Additions and Corrections.
Page	Page	
.		Eleven new woodcuts illustrate Chapter XXVI., borrowed chiefly from my paper on Etna, communicated to the Royal Society in 1858.
444	69	An account is here given of the changes produced by the recent eruption in the Gulf of Santorin in February 1866, with a bird's-eye view of the same.
452	82 to 89	An account of the earthquake in New Zealand in 1855, and the permanent upheaval and subsidence of land in that archipelago, is given on the authority of Messrs. Roberts, Walter Mantell, and F. A. Weld. A new fault or shift of 9 feet in the rocks is described. A map of the region convulsed by the same earthquake is appended.
488	135 to 140	In reference to the earthquakes in Calabria in 1783 and 1857, the origin and mode of the propagation of earthquake waves is treated of, and illustrated by three new diagrams. Some account is given of Mr. Robert Mallet's proposed method of calculating mathematically the depth in the earth's crust from which the shocks may proceed.
494	146	Junghuhn on the truncation of the cone of Papandayang in Java.
529	187	Recent observations made to determine whether a change is going on iu the relative level of land and sea in Sweden.
527	192	Messrs. Gwyn Jeffreys and Torell on shells of the Glacial Period in the Uddevalla district in Sweden.
542	208	The hypothesis of a change in the axis of rotation of the external shell of the earth considered as a possible cause of change of climate.
538 to 542	209 to 213	This Thirty-second Chapter has been in part re-written and enlarged. It is shown that the old notion, that the crystalline rocks, whether stratified or unstratified, such as granite and gneiss, were produced in the lower part of the earth's crust, at the expense of a central nucleus cooling from a state of fusion, must be given up, now that granite is found to be of all ages, and the metamorphic rocks to be altered sedimentary deposits, implying the denudation of a previously solidified crust.
542 to 544	225 to 234	The Thirty-third Chapter has been in great part recast. It is shown that the latest chemical observations on the products of recent eruptions favour the doctrine, that large bodies of salt water gain access, during an eruption, to the volcanic foci. The reservoirs of melted matter in the interior, though vast, may hold a very subordinate place in the earth's crust.
		The heat supposed to be continually lost by the planet by radiation into space, may perhaps be restored by solar magnetism in connection with electricity and chemical action.
Chap. xxxiv. in part.	261 to 283	The greater part of this Thirty-fifth Chapter is new. The objections originally urged against Lamarck's theory of transmutation and his replies are considered. Also the question whether, if new species are created from time to time, their first appearance would have been witnessed by the naturalist. Remarks are offered on the 'Vestiges

Ninth Edition.	Tenth Edition.	Additions and Corrections.
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		of Creation,' and on the theory of 'Natural Selection,' as advocated by Mr. C. Darwin and Mr. A. Wallace. The change of opinion produced by Mr. Darwin's work on 'The Origin of Species' is pointed out, and Dr. Hooker's views on the formation of species in the vegetable world by variation and selection are noticed.
592 593 595 597 600 to 607	284 to 315	This Thirty-sixth Chapter is for the most part new. It contains an explanation of Mr. Darwin's views on the formation of new races by selection, both unconscious and methodical, whether of plants or animals under domestication. His doctrine of 'Pangenesis,' or the manner in which long-lost characters may be revived in the offspring or cross-breeds, is also alluded to. Likewise the fact that certain parts of animals or plants may be made to vary by selection, while other parts of the same remaiu unaltered. The hybridisation of plants and animals is also considered in its bearing on the nature and origin of species.
605	316 to 328	This Thirty-seventh Chapter is also for the most part new. It treats of natural as compared to artificial selection. The tendency of species to multiply beyond the means of subsistence, the struggle for life, and the conditions on which 'the survival of the fittest' depends, are explained. The opinions of Linnæus, de Candolle, and Darwin on species are compared. It is shown that alternate generation will not explain the mode of origin of new species.
629 to 634	329 to 353	Chapter Thirty-eight, on the geographical distribution of species, has been re-written. The six great provinces of distinct species of terrestrial mammalia are chiefly dwelt upon, and the agreement of the limitation of the species of birds and reptiles, and even of the invertebrate animals generally, to the same regions, is pointed out.
636 to 646	354 to 368	Chapter Thirty-nine, on the migration and diffusion of terrestrial animals, is re-printed, with a few slight additions and corrections, from the ninth edition.
637	358	This woodcut of the Lemming or Lapland Marmot, taken from a specimen now living in the Zoological Gardens of London, has been substituted for a less faithful representation of the same animal given in former editions.
646 to 657 and 613 to 628	369 to 401 396	The Fortieth Chapter, on the geographical distribution and migration of fish, testacea, insects and plants, is for the most part the same as in the ninth edition. But the following additions and alterations have been made:—Species of marine shells and fishes on opposite sides of the Isthmus of Panama, p. 370. Moths seen flying 300 miles from land, p. 380. Sir C. Bunbury on plants of the Tableland of Brazil, p. 385. Darwin on seeds and fruits immersed in salt water without injury, p. 321. Robert Brown on source of the gulf-weed or sargassum, p. 392. Darwin on seeds transported by birds, p. 396.
	402 to 432	The Forty-first Chapter is entirely new. It treats of insular floras and faunas considered with reference to the origin of species. The islands of the Eastern Atlantic, especially the Madeiras and Canaries, their volcanic origin and Miocene age, are first treated of, and then the extent to

Ninth Edition.	Tenth Edition.	Additions and Corrections.
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		which the species of mammalia, birds, insects, land-shells and plants, agree or do not agree with continental species. The identity or non-identity, also, of species of all these classes found in different archipelagos or in different islands of the same archipelago, is shown to bear an unmistakable relation to the facilities enjoyed by each class of crossing the ocean. The bearing of this relationship on the theory of the origin of species by variation and 'natural selection' is pointed out.
689 to 701	433 to 463	The Forty-second Chapter, on the extinction of species, is re-printed from the old edition, with some few additions, among which may be mentioned the following:—Dr. Hooker on extermination of plants in St. Helena, pp. 453 and 462. Mr. Travers on the spread of foreign plants in New Zealand, p. 453.
660 to 663	464 to 494	The whole of this Forty-third Chapter, on man, considered with reference to his origin and geographical distribution, is new, with the exception of the first five pages.
		The antiquity of the more marked human races, and the coincidence of their geographical range with that of the chief zoological provinces, are considered. The question as to the multiple origin of man is discussed. The bearing of the theory of progressive development and of Darwin's theory of natural selection on the derivation of man from the inferior animals, is treated of.
746	535	Some remarks on the submarine forest at Bournemouth, on the south coast of Hampshire, are added.
	536	Dr. Dawson's description of a submarine forest on the Bay of Fundy is introduced here.
765	557	A brief sketch is given, in retrospective chronological order, of the remains of man and his works which belong to the ages of Bronze and Stone. Implements of the Neolithic Period—of the antecedent Rein-deer Period—and lastly of the Palæolithic Period, are mentioned. The position of flint tools of Palæolithic age in the drift of the southern coast of Hampshire and the Isle of Wight, is explained.
	564	The age of the pottery in the upraised marine strata near Cagliari, on the south coast of Sardinia, is discussed.
775 to 797	579 to 611	The Forty-ninth Chapter is re-printed from the corresponding or concluding Chapter of the ninth edition, with some corrections in the nomenclature of corals supplied by Dr. Duncan, and some observations at p. 580 on the depths at which different genera grow. Allusion is also made, p. 609, to the large quantity of limestone in the oldest or Laurentian series of rocks in Canada.

CHARLES LYELL.

73 Harley Street:
March 1, 1868.

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PRINCIPLES

OF

GEOLOGY.

CHAPTER I.

GEOLOGY DEFINED—COMPARED TO HISTORY—ITS RELATION TO OTHER PHYSICAL SCIENCES—NOT TO BE CONFOUNDED WITH COSMOGONY.

GEOLOGY is the science which investigates the successive changes that have taken place in the organic and inorganic kingdoms of nature; it enquires into the causes of these changes, and the influence which they have exerted in modifying the surface and external structure of our planet.

By these researches into the state of the earth and its inhabitants at former periods, we acquire a more perfect knowledge of its present condition, and more comprehensive views concerning the laws now governing its animate and inanimate productions. When we study history, we obtain a more profound insight into human nature, by instituting a comparison between the present and former states of society. We trace the long series of events which have gradually led to the actual posture of affairs; and by connecting effects with their causes, we are enabled to classify and retain in the memory a multitude of complicated relations—the various peculiarities of national character—the different degrees of moral and intellectual refinement, and numerous other circumstances, which, without historical associations, would be uninteresting or imperfectly understood. As the present

condition of nations is the result of many antecedent changes, some extremely remote, and others recent, some gradual, others sudden and violent; so the state of the natural world is the result of a long succession of events; and if we would enlarge our experience of the present economy of nature, we must investigate the effects of her operations in former epochs.

We often discover with surprise, on looking back into the chronicles of nations, how the fortune of some battle has influenced the fate of millions of our contemporaries, when it has long been forgotten by the mass of the population. With this remote event we may find inseparably connected the geographical boundaries of a great state, the language now spoken by the inhabitants, their peculiar manners, laws, and religious opinions. But far more astonishing and unexpected are the connections brought to light, when we carry back our researches into the history of nature. The form of a coast, the configuration of the interior of a country, the existence and extent of lakes, valleys, and mountains, can often be traced to the former prevalence of earthquakes and volcanos in regions which have long been undisturbed. To these remote convulsions the present fertility of some districts, the sterile character of others, the elevation of land above the sea, the climate, and various peculiarities, may be distinctly referred. On the other hand, many distinguishing features of the surface may often be ascribed to the operation, at a remote era, of slow and tranquil causes—to the gradual deposition of sediment in the lake or in the ocean, or to the prolific increase of testacea and corals.

To select another example: we find in certain localities subterranean deposits of coal, consisting of vegetable matter, which formerly grew like peat, in swamps, or was drifted into seas and lakes. These seas and lakes have since been filled up, the lands whereon the forests grew have been submerged and covered with new strata, the rivers and currents which floated the vegetable masses can no longer be traced, and the plants belong to species which for ages have passed away from the surface of our planet. Yet the commercial prosperity, and numerical strength of a nation, may now be mainly

dependent on the local distribution of fuel determined by that ancient state of things.

Geology is intimately related to almost all the physical sciences, as history is to the moral. An historian should, if possible, be at once profoundly acquainted with ethics, politics, jurisprudence, the military art, theology; in a word, with all branches of knowledge by which any insight into human affairs, or into the moral and intellectual nature of man, can be obtained. It would be no less desirable that a geologist should be well versed in chemistry, natural philosophy, mineralogy, zoology, comparative anatomy, botany; in short, in every science relating to organic or inorganic nature. With these accomplishments, the historian and geologist would rarely fail to draw correct and philosophical conclusions from the various monuments transmitted to them of former occurrences. They would know to what combination of causes analogous effects were referable, and they would often be enabled to supply, by inference, information concerning many events unrecorded in the defective archives of former ages. But as such extensive acquisitions are scarcely within the reach of any one individual, it is necessary that men who have devoted their lives to different departments should unite their efforts; and as the historian receives assistance from the antiquary, and from those who have cultivated different branches of moral and political science, so the geologist should avail himself of the aid of many naturalists, and particularly of those who have studied the fossil remains of lost species of animals and plants.

The analogy, however, of the monuments consulted in geology, and those available in history, extends no farther than to one class of historical monuments—those which may be said to be *undesignedly* commemorative of former events. The buried coin fixes the date of the reign of some Roman emperor: the ancient encampment indicates the districts once occupied by invading armies, and the former method of constructing military defences; the Egyptian mummies throw light on the art of embalming, the rites of sepulture, or the average stature of the human race in ancient Egypt. The canoes and stone hatchets, called celts, found in our peat-bogs

and estuary deposits, afford an insight into the rude arts and manners of a prehistoric race, to whom the use of metals was unknown, while flint implements of a much ruder type point to a still earlier period, when man coexisted in Europe with many quadrupeds long since extinct. This class of memorials yields to no other in authenticity, but it constitutes a small part only of the resources on which the historian relies, whereas in geology it forms the only kind of evidence which is at our command. For this reason we must not expect to obtain a full and connective account of any series of events beyond the reach of history. But the testimony of geological monuments, if frequently imperfect, possesses at least the advantage of being free from all intentional misrepresentation. We may be deceived in the inferences which we draw, in the same manner as we often mistake the nature and import of phenomena observed in the daily course of nature; but our liability to err is confined to the interpretation, and, if this be correct, our information is certain.

It was long before the distinct nature and legitimate objects of geology were fully recognised, and it was at first confounded with many other branches of enquiry, just as the limits of history, poetry, and mythology were ill defined in the infancy of civilisation. Even in Werner's time, or at the close of the eighteenth century, geology appears to have been regarded as little other than a subordinate department of Mineralogy; and Desmarest included it under the head of Physical Geography. But the most common and serious source of confusion arose from the notion, that it was the business of geology to discover the mode in which the earth originated, or, as some imagined, to study the effects of those cosmological causes which were employed by the Author of Nature to bring this planet out of a nascent and chaotic state into a more perfect and habitable condition. Hutton was the first who endeavoured to draw a strong line of demarcation between his favourite science and cosmogony, for he declared that geology was in nowise concerned 'with questions as to the origin of things.'

An attempt will be made in the sequel of this work to

demonstrate that geology differs as widely from cosmogony, as speculations concerning the mode of the first creation of man differ from history. But, before entering more at large on this controverted question, it will be desirable to trace the progress of opinion on this topic, from the earliest ages to the commencement of the present century.

CHAPTER II.

ORIENTAL COSMOGONY—HYMNS OF THE VEDAS—INSTITUTES OF MENÙ—DOCTRINE OF THE SUCCESSIVE DESTRUCTION AND RENOVATION OF THE WORLD—ORIGIN OF THIS DOCTRINE—COMMON TO THE EGYPTIANS—ADOPTED BY THE GREEKS—ANAXIMANDER ON THE ORIGIN OF MANKIND FROM FISH—SYSTEM OF PYTHAGORAS—OF ARISTOTLE—DOGMAS CONCERNING THE EXTINCTION AND REPRODUCTION OF GENERA AND SPECIES—STRABO'S THEORY OF ELEVATION BY EARTHQUAKES—PLINY—CONCLUDING REMARKS ON THE KNOWLEDGE OF THE ANCIENTS.

Oriental Cosmogony.—The earliest doctrines of the Indian and Egyptian schools of philosophy agreed in ascribing the first creation of the world to an omnipotent and infinite Being. They concurred also in representing this Being, who had existed from all eternity, as having repeatedly destroyed and reproduced the world and all its inhabitants. In the sacred volume of the Hindoos, called the Ordinances of Menù, comprising the Indian system of duties religious and civil, we find a preliminary chapter treating of the Creation, in which the cosmogony is known to have been derived from earlier writings and traditions ; and principally from certain hymns of high antiquity, called the Vedas. These hymns were first put together, according to Mr. Colebrooke,* in a connected series, about thirteen centuries before the Christian era, but they appear from internal evidence to have been written at various antecedent periods. In them, as we learn from the researches of Professor Wilson, the eminent Sanscrit scholar, two distinct philosophical systems are discoverable. According to one of them, all things were originally brought into existence by the sole will of a single First Cause, which existed from eternity; according to the other, there have always existed two principles, the one material, but without

* Essays on the Philosophy of the Hindoos.

form, the other spiritual and capable of compelling 'inert matter to develope its sensible properties.' This development of matter into 'individual and visible existences' is called creation, and is assigned to a subordinate agent, or the creative faculty of the Supreme Being embodied in the person of Brahma.

In the first chapter of the Ordinances of Menù above alluded to, we meet with the following passages relating to former destructions and renovations of the world :—

'The Being, whose powers are incomprehensible, having created me (Menù) and this universe, again became absorbed in the supreme spirit, changing the time of energy for the hour of repose.

'When that Power awakes, then has this world its full expansion ; but when he slumbers with a tranquil spirit, then the whole system fades away. . . . . For while he reposes, as it were, embodied spirits endowed with principles of action depart from their several acts, and the mind itself becomes inert.'

The absorption of all beings into the Supreme essence is then described, and the Divine soul itself is said to slumber and to remain for a time immersed in 'the first idea, or in darkness.' After which the text thus proceeds (verse fifty-seven), 'Thus that immutable power by waking and reposing alternately, revivifies and destroys, in eternal succession, this whole assemblage of locomotive and immovable creatures.'

It is then declared that there has been a long succession of *manwantaras*, or periods, each of the duration of many thousand ages, and—

'There are creations also, and destructions of worlds innumerable: the Being, supremely exalted, performs all this with as much ease as if in sport, again and again, for the sake of conferring happiness.'*

No part of the Eastern cosmogony, from which these extracts are made, is more interesting to the geologist than the doctrine, so frequently alluded to, of the reiterated submersion of the land beneath the waters of an universal ocean.

* Institutes of Hindoo Law, or the Ordinances of Menù, from the Sanscrit, translated by Sir William Jones, 1796.

In the beginning of things, we are told, the First Sole Cause 'with a thought created the waters,' and then moved upon their surface in the form of Brahma the creator, by whose agency the emergence of the dry land was effected, and the peopling of the earth with plants, animals, celestial creatures, and man. Afterwards, as often as a general conflagration at the close of each manwantara had annihilated every visible and existing thing, Brahma, on awaking from his sleep, finds the whole world a shapeless ocean. Accordingly, in the legendary poem called the Puranas, composed at a later date than the Vedas, the three first Avatars or descents of the Deity upon earth have for their object to recover the land from the waters. For this purpose Vishnu is made successively to assume the form of a fish, a tortoise, and a boar.

Extravagant as may be some of the conceits and fictions which disfigure these pretended revelations, we can by no means look upon them as a pure effort of the unassisted imagination, or believe them to have been composed without regard to opinions and theories founded on the observation of Nature. In astronomy, for instance, it is declared that, at the North Pole, the year was divided into a long day and night, and that their long day was the northern, and their night the southern course of the sun; and to the inhabitants of the moon, it is said one day is equal in length to one month of mortals.* If such statements cannot be resolved into mere conjectures, we have no right to refer to chance alone the prevailing notion that the earth and its inhabitants had formerly undergone a succession of revolutions and aqueous catastrophes interrupted by long intervals of tranquillity.

Now, there are two sources in which such a theory may have originated. The marks of former convulsions on every part of the surface of our planet are obvious and striking. The remains of marine animals imbedded in the solid strata are so abundant, that they may be expected to force themselves on the attention of every people who have made some progress in refinement; and especially where one class of

* Menù, Inst. c. i. 66, and 67.

men are expressly set apart from the rest, like the ancient priesthoods of India and Egypt, for study and contemplation. If these appearances are once recognised, it seems natural that the mind should conclude in favour, not only of mighty changes in past ages, but of alternate periods of repose and disorder;—of repose, when the animals now fossil lived, grew and multiplied—of disorder, when the strata in which they were buried became transferred from the sea to the interior of continents, and were uplifted so as to form part of high mountain-chains. Those modern writers, who are disposed to disparage the former intellectual advancement and civilisation of Eastern nations, may concede some foundation of observed facts for the curious theories now under consideration, without indulging in exaggerated opinions of the progress of science; especially as universal catastrophes of the world, and exterminations of organic beings, in the sense in which they were understood by the Brahmins, are untenable doctrines.

We know that the Egyptian priests were aware, not only that the soil beneath the plains of the Nile, but that also the hills bounding the great valley, contained marine shells; and Herodotus inferred from these facts, that all lower Egypt, and even the high lands about Memphis, had once been covered by the sea.* As similar fossil remains occur in all parts of Asia hitherto explored, far in the interior of the continent as well as near the sea, they could hardly have escaped detection by some Eastern sages not less capable than the Greek historian of reasoning philosophically on natural phenomena.

We also know that the rulers of Asia were engaged in very remote eras in executing great national works, such as tanks and canals requiring extensive excavations. In the fourteenth century of our era (in the year 1360), the removal of soil necessary for such undertakings brought to light geological facts, which attracted the attention of a people less civilised than were many of the older nations of the East. The historian Ferishta relates that 50,000 labourers were employed in cutting through a mound, so as to form a junction

* Herodot. Euterpe, 12.

between the rivers Selima and Sutlej; and in this mound were found the bones of elephants and men, some of them petrified, and some of them resembling bone. The gigantic dimensions attributed to the human bones show them to have belonged to some of the larger pachydermata.*

But although the Brahmins, like the priests of Egypt, may have been acquainted with the existence of fossil remains in the strata, it is possible that the doctrine of successive destructions and renovations of the world, merely received corroboration from such proofs; and that it may have been originally handed down, like the religious traditions of most nations, from a ruder state of society. The system may have had its source, in part at least, in exaggerated accounts of those dreadful catastrophes, which are occasioned by particular combinations of natural causes. Floods and volcanic eruptions, the agency of water and fire, are the chief instruments of devastation on our globe. We shall point out in the sequel the extent of many of these calamities, recurring at distant intervals of time, in the present course of nature; and shall only observe here, that they are so peculiarly calculated to inspire a lasting terror, and are so often fatal in their consequences to great multitudes of people, that it scarcely requires the passion for the marvellous, so characteristic of rude and half-civilised nations, still less the exuberant imagination of Eastern writers, to augment them into general cataclysms and conflagrations.

The great flood of the Chinese, which their traditions carry back to the period of Yaou, something more than 2,000 years before our era, has been identified by some persons with the universal deluge described in the Old Testament; but, according to Mr. Davis, who accompanied two of our embassies to China, and who has carefully examined their written accounts, the Chinese cataclysm is therein described as interrupting the business of agriculture, rather than as involving a general destruction of the human race. The

* A Persian MS. copy of the historian Ferishta, in the library of the East India Company, relating to the rise and progress of the Mahomedan empire in India, was procured by Colonel Briggs from the library of Tippoo Sultan in 1799; which has been referred to at some length by Dr. Buckland. (Geol. Trans. 2d Series, vol. ii. part iii. p. 389).

great Yu was celebrated for having 'opened nine channels to draw off the waters,' which 'covered the low hills and bathed the foot of the highest mountains.' Mr. Davis suggests that a great derangement of the waters of the Yellow River, one of the largest in the world, might even now cause the flood of Yaou to be repeated, and lay the most fertile and populous plains of China under water. In modern times the bursting of the banks of an artificial canal, into which a portion of the Yellow River has been turned, has repeatedly given rise to the most dreadful accidents, and is a source of perpetual anxiety to the government. It is easy, therefore, to imagine how much greater may have been the inundation, if this valley was ever convulsed by a violent earthquake.*

Humboldt relates the interesting fact that, after the annihilation of a large part of the inhabitants of Cumana, by an earthquake in 1766, a season of extraordinary fertility ensued, in consequence of the great rains which accompanied the subterranean convulsions. 'The Indians,' he says, 'celebrated, after the ideas of an antique superstition, by festivals and dancing, the destruction of the world and the approaching epoch of its regeneration.'†

The existence of such rites among the rude nations of South America is most important, as showing what effects may be produced by local catastrophes, recurring at distant intervals of time, on the minds of a barbarous and uncultivated race. I shall point out in the sequel how the tradition of a deluge among the Araucanian Indians may be explained, by reference to great earthquake-waves which have repeatedly rolled over part of Chili since the first recorded flood of 1590. The legend also of the ancient Peruvians of an inundation many years before the reign of the Incas, in which only six persons were saved on a float, relates to a region which has more than once been overwhelmed by inroads of the ocean since the days of Pizarro. I might refer the reader to my account of the submergence of a wide area in Cutch so lately as the year 1819, when a single tower only of the fort of Sindree

* See Davis on 'The Chinese,' published by the Soc. for the Diffus. of Use. Know. vol. i. pp. 137, 147.

† Humboldt et Bonpland, Voy. Relat. Hist. vol. i. p. 30.

appeared above the waste of waters, if it were necessary, to prove how easily the catastrophes of modern times might give rise to traditionary narratives, among a rude people, of floods of boundless extent. Nations without written records, and who are indebted for all their knowledge of past events exclusively to oral tradition, are in the habit of confounding in one legend a series of incidents which have happened at various epochs; nor must we forget that the superstitions of a savage tribe are transmitted through all the progressive stages of society, till they exert a powerful influence on the mind of the philosopher. He may find, in the monuments of former changes on the earth's surface, an apparent confirmation of tenets handed down through successive generations, from the rude hunter, whose terrified imagination drew a false picture of those awful visitations of floods and earthquakes, whereby the whole earth as known to him was simultaneously devastated.

Egyptian Cosmogony.—Respecting the cosmogony of the Egyptian priests, we gather much information from writers of the Grecian sects, who borrowed almost all their tenets from Egypt, and amongst others that of the former successive destruction and renovation of the world.* We learn from Plutarch, that this was the theme of one of the hymns of Orpheus, so celebrated in the fabulous ages of Greece. It was brought by him from the banks of the Nile; and we even find in his verses, as in the Indian systems, a definite period assigned for the duration of each successive world.† The returns of great catastrophes were determined by the period of the Annus Magnus, or great year—a cycle composed of the revolutions of the sun, moon, and planets, and terminating when these return together to the same sign whence they were supposed at some remote epoch to have set out. The duration of this great cycle was variously estimated. According to Orpheus, it was 120,000 years; according to others, 300,000; and by Cassander it was taken to be 360,000 years.‡

We learn particularly from the Timæus of Plato, that the

* Prichard's Egypt. Mythol. p. 177.

† Plut. de Defectu Oraculorum, cap. 12. Censorinus de Die Natali. See also Prichard's Egypt. Mythol. p. 182

‡ Prichard's Egypt. Mythol. p. 182.

Egyptians believed the world to be subject to occasional conflagrations and deluges, whereby the gods arrested the career of human wickedness, and purified the earth from guilt. After each regeneration, mankind were in a state of virtue and happiness, from which they gradually degenerated again into vice and immorality. From this Egyptian doctrine, the poets derived the fable of the decline from the golden to the iron age. The sect of Stoics adopted most fully the system of catastrophes destined at certain intervals to destroy the world. These they taught were of two kinds;—the Cataclysm, or destruction by water, which sweeps away the whole human race, and annihilates all the animal and vegetable productions of nature; and the Ecpyrosis, or destruction by fire, which dissolves the globe itself. From the Egyptians also they derived the doctrine of the gradual debasement of man from a state of innocence. Towards the termination of each era the gods could no longer bear with the wickedness of men, and a shock of the elements or a deluge overwhelmed them; after which calamity, Astrea again descended on the earth, to renew the golden age.*

The connection between the doctrine of successive catastrophes and repeated deteriorations in the moral character of the human race is more intimate and natural than might at first be imagined. For, in a rude state of society, all great calamities are regarded by the people as judgments of God on the wickedness of man. Thus, in our own time, the priests persuaded a large part of the population of Chili, and perhaps believed themselves, that the fatal earthquake of 1822 was a sign of the wrath of Heaven for the great political revolution just then consummated in South America. In like manner, in the account given to Solon by the Egyptian priests, of the submersion of the island of Atlantis under the waters of the ocean, after repeated shocks of an earthquake, we find that the event happened when Jupiter had seen the moral depravity of the inhabitants.† Now, when the notion had once gained ground, whether from causes before suggested or not, that the earth had been destroyed by several general catastrophes, it would next be inferred that the

* Prichard's Egypt. Mythol. p. 193.

† Plato's Timæus.

human race had been as often destroyed and renovated. And since every extermination was assumed to be penal, it could only be reconciled with divine justice, by the supposition that man, at each successive creation, was regenerated in a state of purity and innocence.

A very large portion of Asia, inhabited by the earliest nations whose traditions have come down to us, has been always subject to tremendous earthquakes. Of the geographical boundaries of these, and their effects, I shall speak in the proper place. Egypt has, for the most part, been exempt from this scourge, and the Egyptian doctrine of great catastrophes was probably derived in part, as before hinted, from early geological observations, and in part from Eastern nations.

In the Egyptian and Eastern cosmogonies, and in the Greek version of them, no very definite meaning can, in general, be attached to the term 'destruction of the world;' for sometimes it would seem almost to imply the annihilation of our planetary system, and at others a mere revolution of the surface of the earth.

One remarkable fiction of the Egyptian mythology was the supposed intervention of a masculo-feminine principle, to which was assigned the development of the embryo world from chaos, somewhat in the way of incubation. When the first chaotic mass had been produced by a self-dependent and eternal Being, it required the mysterious functions of this subordinate deity to produce the mundane egg from which the whole organised world was developed.

Aristophanes, alluding to this Egyptian fable, which had been engrafted by Orpheus on the Greek mythology, introduced the chorus in his comedy of 'The Birds' singing in a solemn hymn, 'How sable-plumaged Night conceived in the boundless bosom of Erebus, and laid an egg, from which, in the revolution of ages, sprang Love, resplendent with golden pinions. Love fecundated the dark-winged chaos, and gave origin to the race of birds.' *

It is not inconsistent with the Hindoo mythology to suppose that Pythagoras, whose opinions will presently be

* Aristophanes' Birds, p. 694.

mentioned, might have found in the East not only the system of universal and violent catastrophes and periods of repose in endless succession, but also that of periodical revolutions, effected by the continued agency of ordinary causes. For Brahma, Vishnu, and Siva, the first, second, and third persons of the Hindoo triad, severally represented the Creative, the Preserving, and the Destroying powers of the Deity. The co-existence of these three attributes, all in simultaneous operation, might well accord with the notion of perpetual but partial alterations finally bringing about a complete change. But the fiction expressed in the verses before quoted from Menù of eternal vicissitudes in the vigils and slumbers of Brahma seems accommodated to the system of great general catastrophes followed by new creations and periods of repose.

Opinions of the Greeks.—Anaximander (610 b.c.) In the 8th book of Plutarch's Symposiacon or 'Convivial Conversations,' the question is raised why the Pythagoreans were averse to eating fish, and it is considered whether the prejudice may have had an Egyptian, or a Syrian, or an ancient Greek source. One of the party alludes to the doctrine of Anaximander that 'Men were in the beginning engendered in fish, and after they had been nourished and had become able to shift for themselves, they were cast out and took to the land.' A suggestion is then made that, as fish were the parents of mankind, Anaximander may have objected to the use of them as food. Such allusions to an ancient doctrine by no means warrant us in assuming that Anaximander had really taught that men should abstain, from such a motive, from eating fish, but they are curious as affording evidence that the Milesian philosopher really believed that men originally sprang from fish. Unfortunately all the works of Anaximander, the pupil of Thales, are lost. He was born 610 years before Christ, and is said to have been the first who left a philosophical treatise in writing. It is only from a few brief citations scattered through the pages of later authors, that we learn anything of his opinions. Eusebius quotes from a lost work of Plutarch called Στρωματεῖς or 'patchwork,' the following words: 'Man, according to Anaximander, must have been born from animals of a different form (ἐξ ἀλλοειδῶν

ζώων); for whereas other animals easily get their food by themselves, man alone requires long rearing; and no one being such as he was originally, could have been preserved.'*

In another work of Plutarch we read as follows: 'Anaximander taught that the first animals (τὰ πρῶτα ζῶα) were begotten in moisture, and were covered with prickly integuments, but as they grew older they came out into the dry land, and their integuments were rent asunder.'† Censorinus, in his work 'De Die Natali,' says that, according to Anaximander, either fish, or animals very like fish, sprang from heated water and earth, and that the human fœtuses grew in these animals to a state of puberty, so that when at length they burst, men and women capable of nourishing themselves proceeded from them.‡ Full justice cannot, probably, be done to the views of this ancient author by reference to the few meagre fragments of his writings which have alone come down to us, but we trace the same idea running through all of them, namely, the peculiar helplessness of the human infant, making it natural to suppose that there must have been a connection between the embryonic condition of the first human beings and some previously existing animals. Anaximander evidently took for granted that man was not created in an adult or fully developed state, and in so doing he made at least some slight approach, twenty-five centuries before our time, to the modern doctrine of evolution. But none of the above passages warrant the conclusion that the Greek philosopher had anticipated the Lamarckian theory of progressive development. Yet H. Ritter, writing in 1819,§ represents him as having taught that after the first imperfect and short-lived creatures had been engendered in slime, an advance took place from the lower to the higher grades of life, until at length man was formed; and Cuvier, usually so accurate, but who seems never in this instance to have consulted the original texts, went a step beyond Ritter, and said, 'Anaximander pretended that men had been first fish,

* Euseb. Εὐαγγελικῆς προπαρ. 1–8.

† De Placidis Philosophorum, book v. chap. 19.

‡ Censorinus de Die Natali IV.

§ Ersch and Gruber's Encyclopedia, article *Anaximander*.

then reptiles, then mammalia, and lastly what they now are.' 'A system,' he adds, 'which we find reproduced in times very near to our own, and even in the nineteenth century.' 'Quoi qu'il en soit, Anaximandre, ayant admis l'eau comme le second principe de la Nature, prétendait que les hommes avaient primitivement été poissons, puis reptiles, puis mammifères et enfin ce qu'ils sont maintenant, nous retrouverons ce système dans des temps très-rapprochés des nôtres et même dans le dix-neuvième siècle.'*

Pythagorean Doctrines.—Pythagoras (580? B.C.), who resided for more than twenty years in Egypt, and, according to Cicero, had visited the East, and conversed with the Persian philosophers, introduced into his own country, on his return, the doctrine of the gradual deterioration of the human race from an original state of virtue and happiness; but if we are to judge of his theory concerning the destruction and renovation of the earth from the sketch given by Ovid, we must concede it to have been far more philosophical than any known version of the cosmogonies of Oriental or Egyptian sects.

Although Pythagoras is introduced by the poet as delivering his doctrine in person, some of the illustrations are derived from natural events which happened after the death of the philosopher. But notwithstanding these anachronisms, we may regard the account as a true picture of the tenets of the Pythagorean school in the Augustan age; and although perhaps partially modified, it must have contained the substance of the original scheme. Thus considered, it is extremely curious and instructive; for we here find a comprehensive summary of almost all the great causes of change now in activity on the globe, and these adduced in confirmation of a principle of a perpetual and gradual revolution inherent in the nature of our terrestrial system. These doctrines, it is true, are not directly applied to the explanation of geological phenomena; or, in other words, no attempt is made to estimate what may have been in past ages, or what

* Cuvier, Hist. des Sciences naturelles, tome i. p. 91, published in 1841. Lamarck and Geoffroy St. Hilaire are evidently here alluded to: they had derived their theory of progressive development from geological data, the former having published his opinions in 1801, and G. St. Hilaire in 1828.

may hereafter be, the aggregate amount of change brought about by such never-ending fluctuations. Had this been the case, we might have been called upon to admire so extraordinary an anticipation with no less interest than astronomers, when they endeavour to define by what means the Samian philosopher came to the knowledge of the Copernican system.

Let us now examine the celebrated passages to which we have been adverting:—*

'Nothing perishes in this world; but things merely vary and change their form. To be born, means simply that a thing begins to be something different from what it was before; and dying, is ceasing to be the same thing. Yet, although nothing retains long the same image, the sum of the whole remains constant.' These general propositions are then confirmed by a series of examples, all derived from natural appearances, except the first, which refers to the golden age giving place to the age of iron. The illustrations are thus consecutively adduced.

1. Solid land has been converted into sea.

2. Sea has been changed into land. Marine shells lie far distant from the deep, and the anchor has been found on the summit of hills.

3. Valleys have been excavated by running water, and floods have washed down hills into the sea.†

4. Marshes have become dry ground.

5. Dry lands have been changed into stagnant pools.

6. During earthquakes some springs have been closed up, and new ones have broken out. Rivers have deserted their channels, and have been re-born elsewhere; as the Erasinus in Greece, and Mysus in Asia.

7. The waters of some rivers, formerly sweet, have become bitter; as those of the Anigris in Greece, &c.‡

8. Islands have become connected with the main land by

* Ovid's Metamor. lib. 15.

† Eluvie mons est deductus in æquor, v. 267. The meaning of this last verse is somewhat obscure; but taken with the context, may be supposed to allude to the abrading power of floods, torrents, and rivers.

‡ The impregnation from new mineral springs, caused by earthquakes in volcanic countries, is perhaps here alluded to.

the growth of deltas and new deposits; as in the case of Antissa joined to Lesbos, Pharos to Egypt, &c.

9. Peninsulas have been divided from the main land, and have become islands, as Leucadia; and according to tradition Sicily, the sea having carried away the isthmus.

10. Land has been submerged by earthquakes; the Grecian cities of Helice and Buris, for example, are to be seen under the sea, with their walls inclined.

11. Plains have been upheaved into hills by the confined air seeking vent, as at Trœzene in the Peloponnesus.

12. The temperature of some springs varies at different periods. The waters of others are inflammable.* Some streams make the hair to resemble amber and gold, others influence the mind as well as the body, having some of them an exciting, others a soporific effect.

13. There are streams which have a petrifying power, and convert the substances which they touch into marble.

14. Extraordinary medicinal and deleterious effects are produced by water of different lakes and springs.†

15. Some rocks and islands, after floating and having been subject to violent movements, have at length become stationary and immovable, as Delos, and the Cyanean Isles.‡

16. Volcanic vents shift their position; there was a time when Etna was not a burning mountain, and the time will come when it will cease to burn. Whether it be that some caverns become closed up by the movements of the earth, and others opened, or whether the fuel is finally exhausted, &c. &c.

The various causes of change in the inanimate world

* That is probably an allusion to the escape of inflammable gas, like that in the district of Baku, west of the Caspian; at Pietramala, in the Tuscan Apennines; and several other places.

† Many of those described seem fanciful fictions, like the exaggerated virtues still attributed to some mineral waters.

‡ Raspe, in a learned and judicious essay (De Novis Insulis, cap. 19), has made it appear extremely probable that all the traditions of certain islands in the Mediterranean having at some former time frequently shifted their positions, and at length become stationary, originated in the great change produced in their form by earthquakes and submarine eruptions, of which there have been modern examples in the new islands raised in the time of history. When the series of convulsions ended, the island was said to become fixed.

having been thus enumerated, those of the animate creation are next alluded to. The metamorphoses of insects and frogs are mentioned, and some popular notions respecting other changes in the organic world, such as the springing up of the phœnix from the ashes of its parent; but none of the facts or fables have any geological bearing, unless we consider the alleged generation of bees and wasps from the putrid carcases of dead cattle and horses, and the originating of snakes from the marrow of the human spine in sepulchres, as implying the adoption of the doctrine of equivocal generation. The transmigration of souls into the bodies of animals is referred to as having been taught by Numa Pompilius. But there is nothing to prove that the Greeks or Romans had any fixed ideas respecting a general change of species having occurred in the past history of the globe, still less that there had been a progressive development of life from the lowest to the highest grades of organisation. Xenophanes, a Colophonian who lived B.C. 535, spoke of shells, fishes, and seals which had become dried in mud, and were found inland and on the tops of the highest mountains. Aristotle, in his treatise on respiration, speaks distinctly of fossil fishes; and his pupil Theophrastus, alluding to such fishes found near Heraclea, in Pontus, and in Paphlagonia, says, that they were either procreated from fish-spawn left behind in the earth, or had gone astray from rivers or from the sea, for the sake of food, into cavities in the earth, where they had become petrified. The same writer, treating of fossil ivory and bones, supposed them to be produced by a certain plastic virtue latent in our earth.

Opinions of Aristotle.—From the works now extant of Aristotle, and from the system of Pythagoras, as above exposed, we might certainly infer that these philosophers considered the agents of change now operating in nature, as capable of bringing about in the lapse of ages a complete revolution; and the Stagyrite even considers occasional catastrophes, happening at distant intervals of time, as part of the regular and ordinary course of nature. The deluge of Deucalion, he says, affected Greece only, and principally the part called Hellas, and it arose from great inundations of

rivers during a rainy winter. But such extraordinary winters, he says, though after a certain period they return, do not always revisit the same places.*

Censorinus quotes it as Aristotle's opinion, that there were general inundations of the globe, and that they alternated with conflagrations; and that the flood constituted the winter of the Great Year, or astronomical cycle, while the conflagration, or destruction by fire, is the summer or period of greatest heat.† If this passage, as Lipsius supposes, be an amplification, by Censorinus, of what is written, in 'the Meteorics,' it is a gross misrepresentation of the doctrine of the Stagyrite, for the general bearing of his reasoning in that treatise tends clearly in an opposite direction. He refers to many examples of changes now constantly going on, and insists emphatically on the great results which they must produce in the lapse of ages. He instances particular cases of lakes that had dried up, and deserts that had at length become watered by rivers and fertilised. He points to the growth of the Nilotic Delta since the time of Homer, to the shallowing of the Palus Mæotis within sixty years from his own time; and although, in the same chapter, he says nothing of changes in the relative level of land and sea, yet in other parts of the same treatise he speaks of such events in connection with earthquakes.‡ He alludes, for example, to the upheaving of one of the Eolian Islands previous to a volcanic eruption. 'The changes of the earth,' he says, 'are so slow in comparison to the duration of our lives, that they are overlooked (λανθάνει); and the migrations of people after great catastrophes and their removal to other regions, cause the event to be forgotten.'§

When we consider the acquaintance displayed by Aristotle, in his various works, with the destroying and renovating powers of Nature, the introductory and concluding passages of the twelfth chapter of his 'Meteorics' are certainly very remarkable. In the first sentence he says, 'The distribution of land and sea in particular regions does not endure throughout all time, but it becomes sea in those parts where

* Meteor. lib. i. cap. 12.

† De Die Nat.

‡ Lib. ii. cap. 14 15, and 16.

§ Ibid.

it was land, and again it becomes land where it was sea: and there is reason for thinking that these changes take place according to a certain system, and within a certain period.' The concluding observation is as follows:—'As time never fails, and the universe is eternal, neither the Tànais, nor the Nile, can have flowed for ever. The places where they rise were once dry, and there is a limit to their operations; but there is none to time. So also of all other rivers; they spring up, and they perish; and the sea also continually deserts some lands and invades others. The same tracts, therefore, of the earth are not, some always sea, and others always continents, but everything changes in the course of time.'

It seems, then, that the Greeks had not only derived from preceding nations, but had also, in some slight degree, deduced from their own observations, the theory of periodical revolutions in the inorganic world: there is, however, no ground for imagining that they contemplated former changes in the races of animals and plants. Even the fact that marine remains were enclosed in solid rocks, although observed by some, and even made the groundwork of geological speculation, never stimulated the industry or guided the enquiries of naturalists. It is not impossible that the theory of equivocal generation might have engendered some indifference on this subject, and that a belief in the spontaneous production of living beings from the earth or corrupt matter, might have caused the organic world to appear so unstable and fluctuating, that phenomena indicative of former changes would not awaken intense curiosity. The Egyptians, it is true, had taught, and the Stoics had repeated, that the earth had once given birth to some monstrous animals, which existed no longer; but the prevailing opinion seems to have been, that after each great catastrophe the same species of animals were created over again. This tenet is implied in a passage of Seneca, where, speaking of a future deluge, he says, 'Every animal shall be generated anew, and man free from guilt shall be given to the earth.'*

* 'Omne ex integro animal generabitur, dabiturque terris homo inscius scelerum.'—Quæst. Nat. iii. c. 29.

An old Arabian version of the doctrine of the successive revolutions of the globe, translated by Abraham Ecchellensis,* seems to form a singular exception to the general rule, for here we find the idea of different genera and species having been created. The Gerbanites, a sect of astronomers who flourished some centuries before the Christian era, taught as follows:—'That after every period of thirty-six thousand four hundred and twenty-five years, there were produced a pair of *every* species of animal, both male and female, from whom animals might be propagated and inhabit this lower world. But when a circulation of the heavenly orbs was completed, which is finished in that space of years, *other genera and species* of animals are propagated, as also of plants and other things, and the first order is destroyed, and so it goes on for ever and ever.' †

Theory of Strabo.—As we learn much of the tenets of the Egyptian and Oriental schools in the writings of the Greeks, so, many speculations of the early Greek authors are made known to us in the works of the Augustan and later ages. Strabo, in particular, enters largely, in the second book of his Geography, into the opinions of Eratosthenes and other Greeks on one of the most difficult problems in geology, viz. by what cause marine shells came to be plentifully buried in the earth at such great elevations and distances from the sea.

* This author was Regius Professor of Syriac and Arabic at Paris, where, in 1685, he published a Latin translation of many Arabian MSS. on different departments of philosophy. This work has always been considered of high authority.

† 'Gerbanitæ docebant singulos triginta sex mille annos quadringentos, viginti quinque bina ex singulis animalium speciebus produci, marem scilicet ac feminam ex quibus animalia propagantur, huncque inferiorem incolunt orbem. Absolutâ autem cœlestium orbium circulatione, quæ illo annorum conficitur spatio, iterum alia producuntur animalium genera et species, quemadmodum et plantarum aliarumque rerum, et primus destruitur ordo, sicque in infinitum producitur.'—Histor. Orient. Suppl. per Abrahamum Ecchellensem, Syrum Maronitam, cap. 7 et 8, ad calcem Chronici Orientali. Parisiis, e Typ. Regia, 1685, fol.

I have given the punctuation as in the Paris edition, there being no comma after quinque; but, at the suggestion of M. de Schlegel, I have referred the number twenty-five to the period of years, and not to the number of pairs of each species created at one time, as I had done in the first two editions.

Fortis inferred that twenty-five new *species* only were created at a time; a construction which the passage will not admit. Mém. sur l'Hist. nat. de l'Italie, vol. i. p. 202.

He notices, amongst others, the explanation of Xanthus the Lydian, who said that the seas had once been more extensive, and that they had afterwards been partially dried up, as in his own time many lakes, rivers, and wells in Asia had failed during a season of drought. Treating this conjecture with merited disregard, Strabo passes on to the hypothesis of Strato, the natural philosopher, who had observed that the quantity of mud brought down by rivers into the Euxine was so great, that its bed must be gradually raised, while the rivers still continued to pour in an undiminished quantity of water. He therefore conceived that, originally, when the Euxine was an inland sea, its level had by this means become so much elevated that it burst its barrier near Byzantium, and formed a communication with the Propontis; and this partial drainage, he supposed, had already converted the left side into marshy ground, and thus, at last, the whole would be choked up with soil. So, it was argued, the Mediterranean had once opened a passage for itself by the Columns of Hercules into the Atlantic; and perhaps the abundance of sea-shells in Africa, near the Temple of Jupiter Ammon, might also be the deposit of some former inland sea, which had at length forced a passage and escaped.

But Strabo rejects this theory, as insufficient to account for all the phenomena, and he proposes one of his own, the profoundness of which modern geologists are only beginning to appreciate. 'It is not,' he says, 'because the lands covered by seas were originally at different altitudes, that the waters have risen, or subsided, or receded from some parts and inundated others. But the reason is, that the same land is sometimes raised up and sometimes depressed, and the sea also is simultaneously raised and depressed, so that it either overflows or returns into its own place again. We must, therefore, ascribe the cause to the ground, either to that ground which is under the sea, or to that which becomes flooded by it, but rather to that which lies beneath the sea, for this is more movable and, on account of its humidity, can be altered with greater celerity.* *It is proper,'* he

* 'Quod enim hoc attollitur aut subsidit, et vel inundat quædam loca, vel ab iis recedit, ejus rei causa non est quod alia aliis sola humiliora sint aut

observes in continuation, '*to derive our explanations from things which are obvious, and in some measure of daily occurrence, such as deluges, earthquakes, and volcanic eruptions,* and sudden swellings of the land beneath the sea*; for the last raise up the sea also; and when the same lands subside again, they occasion the sea to be let down. And it is not merely the small, but the large islands also, and not merely the islands, but the continents which can be lifted up together with the sea; and both large and small tracts may subside, for habitations and cities, like Bure, Bizona, and many others, have been engulphed by earthquakes.'

In another place this learned geographer, in alluding to the tradition that Sicily had been separated by a convulsion from Italy, remarks, that at present the land near the sea in those parts was rarely shaken by earthquakes, since there were now open orifices whereby fire and ignited matters, and waters escape; but formerly, when the volcanos of Etna, the Lipari Islands, Ischia, and others, were closed up, the imprisoned fire and wind might have produced far more vehement movements.† The doctrine, therefore, that volcanos are safety-valves, and that the subterranean convulsions are probably most violent when first the volcanic energy shifts itself to a new quarter, is not modern.

We learn from a passage in Strabo,‡ that it was a dogma of the Gaulish Druids that the universe was immortal, but destined to survive catastrophes both of fire and water. That this doctrine was communicated to them from the East, with much of their learning, cannot be doubted. Cæsar, it will be remembered, says that they made use of Greek letters in arithmetical computations.§

Pliny, A.D. 23.—This philosopher had no theoretical

altiora; sed quod idem solum modò attollitur modò deprimitur, simulque etiam modò attollitur modò deprimitur, mare: itaque vel exundat vel in suum redit locum.'

Posteà, p. 88. 'Restat, ut causam adscribamus solo, sive quod mari subest sive quod inundatur; potiùs tamen ei quod mari subest. Hoc enim multò est mobilius, et quod ob humiditatem celeriùs multari possit.'—Strabo, Geog. Edit. Almelov. Amst. 1707, lib. i.

* *Volcanic eruptions*, eruptiones flatuum, in the Latin translations, and in the original Greek, ἀναφυσήματα, gaseous eruptions? or *inflations* of land? Ibid. p. 93.

† Strabo. lib. vi. p. 396.

‡ Book iv.

§ L. vi. ch. xiii.

opinions of his own concerning changes of the earth's surface; and in this department, as in others, he restricted himself to the task of a compiler, without reasoning on the facts stated by him, or attempting to digest them into regular order. But his enumeration of the new islands which had been formed in the Mediterranean, and of other convulsions, shows that the ancients had not been inattentive observers of the changes which had taken place within the memory of man.

Such, then, appear to have been the opinions entertained before the Christian era, concerning the past revolutions of our globe. Although no particular investigations had been made for the express purpose of interpreting the monuments of ancient changes, they were too obvious to be entirely disregarded ; and the observation of the present course of nature presented too many proofs of alterations continually in progress on the earth to allow philosophers to believe that nature was in a state of rest, or that the surface had remained, and would continue to remain, unaltered. But they had never compared attentively the results of the destroying and reproductive operations of modern times with those of remote eras, nor had they ever entertained so much as a conjecture concerning the comparative antiquity of the human race, or of living species of animals and plants, with those belonging to former conditions of the organic world. They had studied the movements and positions of the heavenly bodies with laborious industry, and made some progress in investigating the animal, vegetable, and mineral kingdoms; but the ancient history of the globe was to them a sealed book, and, although written in characters of the most striking and imposing kind, they were unconscious even of its existence.

CHAPTER III.

HISTORY OF THE PROGRESS OF GEOLOGY—*continued.*

ARABIAN WRITERS OF THE TENTH CENTURY—AVICENNA—OMAR—COSMOGONY OF THE KORAN—KAZWINI—EARLY ITALIAN WRITERS—LEONARDO DA VINCI—FRACASTORO—CONTROVERSY AS TO THE REAL NATURE OF FOSSILS—ATTRIBUTED TO THE MOSAIC DELUGE—PALISSY—STENO—SCILLA—QUIRINI—BOYLE—LISTER—LEIBNITZ—HOOKE'S THEORY OF ELEVATION BY EARTHQUAKES—OF LOST SPECIES OF ANIMALS—RAY—PHYSICO-THEOLOGICAL WRITERS—WOODWARD'S DILUVIAL THEORY—BURNET—WHISTON—VALLISNERI—LAZZARO MORO—GENERELLI—BUFFON—HIS THEORY CONDEMNED BY THE SORBONNE AS UNORTHODOX—HIS DECLARATION—TARGIONI—ARDUINO—MICHELL—CATCOTT—RASPE—FUCHSEL—FORTIS—TESTA—WHITEHURST—PALLAS—SAUSSURE.

Arabian writers.—After the decline of the Roman empire, the cultivation of physical science was first revived with some success by the Saracens, about the middle of the eighth century of our era. The works of the most eminent classic writers were purchased at great expense from the Christians, and translated into Arabic; and Al Mamûn, son of the famous Harûn-al-Rashid, the contemporary of Charlemagne, received with marks of distinction, at his court at Bagdad, astronomers and men of learning from different countries. This caliph, and some of his successors, encountered much opposition and jealousy from the doctors of the Mahometan law, who wished the Moslems to confine their studies to the Koran, dreading the effects of a diffusion of a taste for the physical sciences.*

Avicenna.—Almost all the works of the early Arabian writers are lost. Amongst those of the tenth century, of which fragments are now extant, is a short treatise, 'On the Formation and Classification of Minerals,' by Avicenna, a physician,

* Mod. Univ. Hist. vol. ii. chap. iv. section iii.

in whose arrangement there is considerable merit. The second chapter, 'On the Cause of Mountains,' is remarkable; for mountains, he says, are formed, some by essential, others by accidental causes. In illustration of the essential, he instances 'a violent earthquake, by which land is elevated, and becomes a mountain;' of the accidental, the principal, he says, is excavation by water, whereby cavities are produced, and adjoining lands made to stand out and form eminences.*

Omar—Cosmogony of the Koran.—In the same century also, Omar, surnamed 'El Aalem,' or 'The Learned,' wrote a work on 'The Retreat of the Sea.' It appears that on comparing the charts of his own time with those made by the Indian and Persian astronomers two thousand years before, he had satisfied himself that important changes had taken place since the times of history in the form of the coasts of Asia, and that the extension of the sea had been greater at some former periods. He was confirmed in this opinion by the numerous salt springs and marshes in the interior of Asia,—a phenomenon from which Pallas, in more recent times, has drawn the same inference.

Von Hoff has suggested, with great probability, that the changes in the level of the Caspian (some of which there is reason to believe have happened within the historical era), and the geological appearances in that district, indicating the desertion by that sea of its ancient bed, had probably led Omar to his theory of a general lowering of the waters. But whatever may have been the proofs relied on, his system was declared contradictory to certain passages in the Koran, and he was called upon publicly to recant his errors; to avoid which persecution he went into voluntary banishment from Samarkand.†

* 'Montes quandòque fiunt ex causa essentiali, quandòque ex causa accidentali. Ex essentiali causa, ut ex vehementi motu terræ elevatur terra, et fit mons. Accidentali, &c.'—De Congelatione Lapidum, ed. Gedani, 1682.

† Von Hoff, Geschichte der Veränderungen der Erdoberfläche, vol. i. p. 406, who cites Delisle, bey Hismann, Welt- und Völkergeschichte. Alte Geschichte, 1ter Theil, s. 234.—The Arabian persecutions for heretical dogmas in theology were often very sanguinary. In the same ages wherein learning was most in esteem, the Mahometans were divided into two sects, one of whom maintained that the Koran was increate and had subsisted in the very essence of God for all eternity; and the other, the Motazalites, who, admitting that the

The cosmological opinions expressed in the Koran are few, and merely introduced incidentally: so that it is not easy to understand how they could have interfered so seriously with free discussion on the former changes of the globe. The Prophet declares that the earth was created in two days, and the mountains were then placed on it; and during these, and two additional days, the inhabitants of the earth were formed; and in two more the seven heavens.* There is no more detail of circumstances; and the deluge, which is also mentioned, is discussed with equal brevity. The waters are represented to have poured out of an oven; a strange fable, said to be borrowed from the Persian Magi, who represented them as issuing from the oven of an old woman.† All men were drowned, save Noah and his family; and then God said, 'O earth, swallow up thy waters; and thou, O heaven, withhold thy rain;' and immediately the waters abated.‡

We may suppose Omar to have represented the desertion of the land by the sea to have been gradual, and that his hypothesis required a greater lapse of ages than was consistent with Moslem orthodoxy; for it is to be inferred from the Koran, that man and his planet were created at the same time; and although Mahomet did not limit expressly the antiquity of the human race, yet he gave an implied sanction to the Mosaic chronology, by the veneration expressed by him for the Hebrew Patriarchs.§

A manuscript work, entitled the 'Wonders of Nature,' is preserved in the Royal Library at Paris, by an Arabian writer, Mohammed Kazwini, who flourished in the seventh century of the Hegira, or at the close of the thirteenth century of our era.‖ Besides several curious remarks on aerolites,

Koran was instituted by God, conceived it to have been first made when revealed to the Prophet at Mecca, and accused their opponents of believing in two eternal beings. The opinions of each of these sects were taken up by different caliphs in succession, and the followers of each sometimes submitted to be beheaded, or flogged till at the point of death, rather than renounce their creed.—Mod. Univ. Hist. vol. ii. ch. iv.

* Koran, chap. xli.

† Sale's Koran, chap, xi. see note.

‡ Ibid.

§ Kossa, appointed master to the Caliph Al Mamûd, was author of a book entitled 'The History of the Patriarchs and Prophets, *from the Creation of the World*.'—Mod. Univ. Hist. vol. ii. ch. iv.

‖ Translated by MM. Chezy and De Sacy, and cited by M. Elie de Beaumont, Ann. des Sci. nat. 1832.

earthquakes, and the successive changes of position which the land and sea have undergone, we meet with the following beautiful passage which is given as the narrative of Kidhz, an allegorical personage:—'I passed one day by a very ancient and wonderfully populous city, and asked one of its inhabitants how long it had been founded. "It is indeed a mighty city," replied he; "we know not how long it has existed, and our ancestors were on this subject as ignorant as ourselves." Five centuries afterwards, as I passed by the same place, I could not perceive the slightest vestige of the city. I demanded of a peasant, who was gathering herbs upon its former site, how long it had been destroyed. "In sooth a strange question!" replied he. "The ground here has never been different from what you now behold it."—"Was there not of old," said I, "a splendid city here?"—"Never," answered he, "so far as we have seen, and never did our fathers speak to us of any such." On my return there 500 years afterwards, *I found the sea in the same place*, and on its shores were a party of fishermen, of whom I enquired how long the land had been covered by the waters? "Is this a question," said they, "for a man like you? this spot has always been what it is now." I again returned, 500 years afterwards, and the sea had disappeared; I enquired of a man who stood alone upon the spot, how long ago this change had taken place, and he gave me the same answer as I had received before. Lastly, on coming back again after an equal lapse of time, I found there a flourishing city, more populous and more rich in beautiful buildings, than the city I had seen the first time, and when I would fain have informed myself concerning its origin, the inhabitants answered me, "Its rise is lost in remote antiquity: we are ignorant how long it has existed, and our fathers were on this subject as ignorant as ourselves."'

Early Italian Writers.—It was not till the earlier part of the sixteenth century that geological phenomena began to attract the attention of the Christian nations. At that period a very animated controversy sprang up in Italy, concerning the true nature and origin of marine shells, and other organised fossils, found abundantly in the strata of the peninsula. The cele-

brated painter Leonardo da Vinci, who in his youth had planned and executed some navigable canals in the north of Italy, was one of the first who applied sound reasoning to these subjects. The mud of rivers, he said, had covered and penetrated into the interior of fossil shells at a time when these were still at the bottom of the sea near the coast. 'They tell us that these shells were formed in the hills by the influence of the stars; but I ask where in the hills are the stars now forming shells of distinct ages and species? and how can the stars explain the origin of gravel, occurring at different heights and composed of pebbles rounded as if by the motion of running water; or in what manner can such a cause account for the petrifaction in the same places of various leaves, sea-weeds, and marine crabs?' *

The excavations made in 1517, for repairing the city of Verona, brought to light a multitude of curious petrifactions, and furnished matter for speculation to different authors, and among the rest to Fracastoro,† who declared his opinion, that fossil shells had all belonged to living animals, which had formerly lived and multiplied where their exuviæ are now found. He exposed the absurdity of having recourse to the 'plastic force' of Theophrastus (see above, p. 20) which had power to fashion stones into organic forms; and with no less cogent arguments, demonstrated the futility of attributing the situation of the shells in question to the Mosaic deluge, a theory obstinately defended by some. That inundation, he observed, was too transient: it consisted principally of fluviatile waters; and if it had transported shells to great distances, must have strewed them over the surface, not buried them at vast depths in the interior of mountains. His clear exposition of the evidence would have terminated the discussion for ever, if the passions of mankind had not been enlisted in the dispute; and even though doubts should for a time have remained in some minds, they would

* See Venturi's extracts from Da Vinci's MSS. now in Library of Institute of France. They are not mentioned by Brocchi, and my attention was first called to them by Mr. Hallam. L. da Vinci died A.D. 1519.

† Museum Calceol.—See Brocchi's Discourse on the Progress of the Study of Fossil Conchology in Italy, where some of the following notices on Italian writers will be found more at large.

speedily have been removed by the fresh information obtained almost immediately afterwards, respecting the structure of fossil remains, and of their living analogues.

But the clear and philosophical views of Fracastoro were disregarded, and the talent and the argumentative powers of the learned were doomed for three centuries to be wasted in the discussion of these two simple and preliminary questions; first, whether fossil remains had ever belonged to living creatures; and, secondly, whether, if this be admitted, all the phenomena could not be explained by the deluge of Noah. It had been the general belief of the Christian world down to the period now under consideration, that the origin of this planet was not more remote than a few thousand years; and that since the creation the deluge was the only great catastrophe by which considerable change had been wrought on the earth's surface. On the other hand, the opinion was scarcely less general, that the final dissolution of our system was an event to be looked for at no distant period. The era, it is true, of the expected millennium had passed away; and for five hundred years after the fatal hour when the annihilation of the planet had been looked for, the monks remained in undisturbed enjoyment of rich grants of land bequeathed to them by pious donors, who, in the preamble of deeds beginning 'appropinquante mundi termino'——'appropinquante magno judicii die,' left lasting monuments of the popular delusion.*

But although in the sixteenth century it had become necessary to interpret certain prophecies respecting the millennium more liberally, and to assign a more distant date to the future conflagration of the world, we find, in the speculations of the early geologists, perpetual allusion to such an approaching catastrophe; while in all that regarded the antiquity of the earth, no modification whatever of the opinions of the dark ages had been effected. Considerable alarm was at first excited when the attempt was made to invalidate, by physical proofs, an article of faith so generally

* In Sicily, in particular, the title-deeds of many valuable grants of land to the monasteries are headed by such preambles, composed by the testators about the period when the good King Roger was expelling the Saracens from that island.

received; but there was sufficient spirit of toleration and candour amongst the Italian ecclesiastics, to allow the subject to be canvassed with much freedom. They even entered warmly into the controversy themselves, often favouring different sides of the question; and however much we may deplore the loss of time and labour devoted to the defence of untenable positions, it must be conceded that they displayed far less polemic bitterness than certain writers who followed them 'beyond the Alps,' two centuries and a half later.

CONTROVERSY AS TO THE REAL NATURE OF FOSSIL ORGANIC REMAINS.

Mattioli—Falloppio, 1500–1523.—The system of scholastic disputations, encouraged in the universities of the middle ages, had unfortunately trained men to habits of indefinite argumentation; and they often preferred absurd and extravagant propositions, because greater skill was required to maintain them; the end and object of these intellectual combats being victory, and not truth. No theory could be so far-fetched or fantastical as not to attract some followers, provided it fell in with popular notions; and as cosmogonists were not at all restricted, in building their systems, to the agency of known causes, the opponents of Fracastoro met his arguments by feigning imaginary causes, which differed from each other rather in name than in substance. Andrew Mattioli, for instance, an eminent botanist, the illustrator of Dioscorides, embraced the notion of Agricola, a skilful German miner, that a certain 'materia pinguis,' or 'fatty matter,' set into fermentation by heat, gave birth to fossil organic shapes. Yet Mattioli had come to the conclusion, from his own observations, that porous bodies, such as bones and shells, might be converted into stone, as being permeable to what he termed the 'lapidifying juice.' In like manner, Falloppio of Padua conceived that petrified shells were generated by fermentation in the spots where they are found, or that they had in some cases acquired their form from 'the tumultuous movements of terrestrial exhalations.' Although celebrated as a professor of anatomy, he taught

that certain tusks of elephants, dug up in his time in Apulia, were mere earthy concretions; and, consistently with these principles, he even went so far as to consider it probable, that the vases of Monte Testaceo at Rome were natural impressions stamped in the soil.* In the same spirit, Mercati, who published, in 1574, faithful figures of the fossil shells preserved by Pope Sixtus V. in the Museum of the Vatican, expressed an opinion that they were mere stones, which had assumed their peculiar configuration from the influence of the heavenly bodies: and Olivi of Cremona, who described the fossil remains of a rich museum at Verona, was satisfied with considering them as mere 'sports of nature.'

Some of the fanciful notions of those times were deemed less unreasonable, as being somewhat in harmony with the Aristotelian theory of spontaneous generation, then taught in all the schools.† For men who had been taught in early youth, that a large proportion of living animals and plants were formed from the fortuitous concourse of atoms, or had sprung from the corruption of organic matter, might easily persuade themselves, that organic shapes, often imperfectly preserved in the interior of solid rocks, owed their existence to causes equally obscure and mysterious.

Cardano, 1552.—But there were not wanting some who, during the progress of this century, expressed more sound and sober opinions. The title of a work of Cardano's, published in 1552, 'De Subtilitate' (corresponding to what would now be called Transcendental Philosophy), would lead us to expect, in the chapter on minerals, many far-fetched theories characteristic of that age; but when treating of petrified shells, he decided that they clearly indicated the former sojourn of the sea upon the mountains.‡

Cesalpino—Majoli, 1597.—Cesalpino, a celebrated botanist, conceived that fossil shells had been left on the land by the retiring sea, and had concreted into stone during the consolidation of the soil; § and in the following year (1597), Simeone Majoli || went still farther; and, coinciding for the most

* De Fossilib. pp. 109 and 176.

† Aristotle, On Animals, chapters 1 and 15.

‡ Brocchi, Con. Fos. Subap. Disc. sui Progressi, vol. i. p. 57.

§ De Metallicis.

|| Dies Caniculares.

part with the views of Cesalpino, suggested that the shells and submarine matter of the Veronese, and other districts, might have been cast up upon the land by volcanic explosions, like those which gave rise, in 1538, to Monte Nuovo, near Puzzuoli. This hint seems to have been the first imperfect attempt to connect the position of fossil shells with the agency of volcanos, a system afterwards more fully developed by Hooke, Lazzaro Moro, Hutton, and other writers.

Two years afterwards, Imperati advocated the animal origin of fossil shells, yet admitted that stones could vegetate by force of 'an internal principle;' and, as evidence of this, he referred to the teeth of fish and spines of echini found petrified.*

Palissy, 1580.—Palissy, a French writer on 'The Origin of Springs from Rain-water,' and of other scientific works, undertook, in 1580, to combat the notions of many of his contemporaries in Italy, that petrified shells had all been deposited by the universal deluge. 'He was the first,' said Fontenelle, when, in the French Academy, he pronounced his eulogy, nearly a century and a half later, 'who dared assert,' in Paris, that fossil remains of testacea and fish had once belonged to marine animals.

Fabio Colonna, 1592.—To enumerate the multitude of Italian writers, who advanced various hypotheses, all equally fantastical, in the early part of the seventeenth century, would be unprofitably tedious; but Fabio Colonna deserves to be distinguished; for, although he gave way to the dogma, that all fossil remains were to be referred to the deluge of Noah, he resisted the absurd theory of Stelluti, who taught that fossil wood and ammonites were mere clay, altered into such forms by sulphureous waters and subterranean heat; and he pointed out the different states of shells buried in the strata, distinguishing between, first, the mere mould or impression; secondly, the cast or nucleus; and, thirdly, the remains of the shell itself. He had also the merit of being the first to point out, that some of the fossils had belonged to marine and some to terrestrial testacea.†

* Storia Naturale.

† Osserv. sugli Animali aquat. e terrest. 1626.

Steno, 1669.—But the most remarkable work of that period was published by Steno, a Dane, once professor of anatomy at Padua, and who afterwards resided many years at the court of the Grand Duke of Tuscany. His treatise bears the quaint title of 'De Solido intra Solidum naturaliter contento (1669),' by which the author intended to express, 'On Gems, Crystals, and organic Petrifactions inclosed within solid Rocks.' This work attests the priority of the Italian school in geological research; exemplifying at the same time the powerful obstacles opposed, in that age, to the general reception of enlarged views in the science. It was still a favourite dogma, that the fossil remains of shells and marine creatures were not of animal origin; an opinion adhered to by many from their extreme reluctance to believe, that the earth could have been inhabited by living beings before a great part of the existing mountains were formed. In reference to this controversy, Steno had dissected a shark recently taken from the Mediterranean, and had demonstrated that its teeth and bones were identical with many fossils found in Tuscany. He had also compared the shells discovered in the Italian strata with living species, pointed out their resemblance, and traced the various gradations from shells which had only lost their animal gluten, to those petrifactions in which there was a perfect substitution of stony matter. In his division of mineral masses, he insisted on the secondary origin of those deposits in which the spoils of animals or fragments of older rocks were inclosed. He distinguished between marine formations and those of a fluviatile character, the last containing reeds, grasses, or the trunks and branches of trees. He argued in favour of the original horizontality of sedimentary deposits, attributing their present inclined and vertical position sometimes to the escape of subterranean vapours heaving the crust of the earth from below upwards, and sometimes to the falling in of masses overlying subterranean cavities.

He declared that he had obtained proof that Tuscany must successively have acquired six distinct configurations, having been twice covered by water, twice laid dry with a level,

and twice with an irregular and uneven surface.* He displayed great anxiety to reconcile his new views with Scripture, for which purpose he pointed to certain rocks as having been formed before the existence of animals and plants: selecting unfortunately as examples certain formations of limestone and sandstone in his adopted country, now known to contain, though sparingly, the remains of animals and plants,—strata which do not even rank as the oldest part of our secondary series.

Scilla, 1670.—Scilla, a Sicilian painter, published, in 1670, a treatise, in Latin, on the fossils of Calabria, illustrated by good engravings. This work proves the continued ascendency of dogmas often refuted; for we find the wit and eloquence of the author chiefly directed against the obstinate incredulity of naturalists as to the organic nature of fossil shells. He quotes the remark of Cicero on the story that a stone in Chios had been cleft open, and presented the head of Paniscus in relief:—'I believe,' says Cicero, 'that the figure bore some resemblance to Paniscus, but not such that you would have deemed it sculptured by Scopas; for chance never perfectly imitates the truth.' Like many eminent naturalists of his day, Scilla seems to give way to the popular persuasion, that all fossil shells were the effects and proofs of the Mosaic deluge.

Diluvial Theory.—The theologians who now entered the field in Italy, Germany, France, and England, were innumerable; and henceforward, they who refused to subscribe to the position, that all marine organic remains were proofs of the Mosaic deluge, were exposed to the imputation of disbelieving the whole of the sacred writings. Scarcely any step had been made in approximating to sound theories since the time of Fracastoro, more than a hundred years having been lost, in writing down the dogma that organised fossils were mere sports of nature. An additional period of a century and a half was now destined to be consumed in exploding the hypothesis, that organised fossils had all been buried in the solid strata by Noah's flood. Never did a

* 'Sex itaque distinctas Etruriæ facies agnoscimus, dum bis fluida, bis plana, et sicca, bis aspera fuerit,' &c.

theoretical fallacy, in any branch of science, interfere more seriously with accurate observation and the systematic classification of facts. In recent times, we may attribute our rapid progress chiefly to the careful determination of the order of succession in mineral masses, by means of their different organic contents, and their regular superposition. But the old diluvialists were induced by their system to confound all the groups of strata together, referring all appearances to one cause and to one brief period, not to a variety of causes acting throughout a long succession of epochs. They saw the phenomena only, as they desired to see them, sometimes misrepresenting facts, and at other times deducing false conclusions from correct data. In short, a sketch of the progress of geology from the close of the seventeenth to the end of the eighteenth century is the history of a constant and violent struggle of new opinions against doctrines sanctioned by the implicit faith of many generations, and supposed to rest on scriptural authority.

Quirini, 1676.—Quirini, in 1676,* contended, in opposition to Scilla, that the diluvial waters could not have conveyed heavy bodies to the summit of mountains, since the agitation of the sea never, as Boyle had demonstrated, extended to great depths; and still less could the testacea, as some pretended, have lived in these diluvial waters; for 'the duration of the flood was brief, and *the heavy rains must have destroyed the saltness of the sea!*' The opinions of Boyle, alluded to by Quirini, were published a few years before, in a short article entitled 'On the Bottom of the Sea.' From observations collected from the divers of the pearl fishery, Boyle inferred that, when the waves were six or seven feet high above the surface of the water, there were no signs of agitation at the depth of fifteen fathoms; and that even during heavy gales of wind, the motion of the water was exceedingly diminished at the depth of twelve or fifteen feet. He had also learnt from some of his informants, that there were currents running in opposite directions at different depths.† Quirini was the first writer who

* De Testaceis fossilibus Mus. Septaliani.

† Boyle's Works, vol. iii. p. 110. London, 1744

ventured to maintain that the universality of the Mosaic cataclysm ought not to be insisted upon. As to the nature of petrified shells, he conceived that as earthy particles united in the sea to form the shells of mollusca, the same crystallising process might be effected on the land; and that, in the latter case, the germs of animals might have been disseminated through the substance of the rocks, and afterwards developed by virtue of humidity. Visionary as was this doctrine, it gained many proselytes even amongst the more sober reasoners of Italy and Germany; for it conceded that the position of fossil bodies could not be accounted for by the diluvial theory.

Plot—Lister, 1678.—In the meantime, the doctrine that fossil shells had never belonged to real animals maintained its ground in England, where the agitation of the question began at a much later period. Dr. Plot, in his 'Natural History of Oxfordshire' (1677), attributed to a 'plastic virtue latent in the earth' the origin of fossil shells and fishes; and Lister, to his accurate account of British shells, in 1678, added the fossil species under the appellation of *turbinated and bivalve stones.* 'Either,' said he, 'these were terriginous, or, if otherwise, the animals they so exactly represent *have become extinct.*' This writer appears to have been the first who was aware of the continuity over large districts of the principal groups of strata in the British series, and who proposed the construction of regular geological maps.*

Leibnitz, 1680.—The great mathematician Leibnitz published his 'Protogœa' in 1680. He imagined this planet to have been originally a burning luminous mass, which ever since its creation has been undergoing refrigeration. When the outer crust had cooled down sufficiently to allow the vapours to be condensed, they fell, and formed a universal ocean, covering the loftiest mountains, and investing the whole globe. The crust, as it consolidated from a state of fusion, assumed a vesicular and cavernous structure; and being rent in some places, allowed the water to rush into the

* See Conybeare and Phillips, 'Outlines of the Geology of England and Wales,' p. 12.

subterranean hollows, whereby the level of the primeval ocean was lowered. The breaking in of these vast caverns is supposed to have given rise to the dislocated and deranged position of the strata 'which Steno had described,' and the same disruptions communicated violent movements to the incumbent waters, whence great inundations ensued. The waters, after they had been thus agitated, deposited their sedimentary matter during intervals of quiescence, and hence the various stony and earthy strata. 'We may recognise, therefore,' says Leibnitz, 'a double origin of primitive masses, the one by refrigeration from igneous fusion, the other by consolidation from aqueous solution.' By the repetition of similar causes (the disruption of the crust and consequent floods), alternations of new strata were produced until at length these causes were reduced to a condition of quiescent equilibrium, and a more permanent state of things was established.*

Hooke, 1668.—The 'Posthumous Works of Robert Hooke, M.D.,' well known as a great mathematician and natural philosopher, appeared in 1705, containing 'A Discourse on Earthquakes,' which we are informed by his editor, was written in 1688, but revised at subsequent periods. Hooke frequently refers to the best Italian and English authors who wrote before his time on geological subjects; but there are no passages in his works implying that he participated in the enlarged views of Steno and Lister, or of his contemporary, Woodward, as to the geographical extent of certain groups of strata. His treatise, however, is the most philosophical production of that age, in regard to the causes of former changes in the organic and inorganic kingdoms of nature.

'However trivial a thing,' he says, 'a rotten shell may appear to some, yet these monuments of nature are more certain tokens of antiquity than coins or medals, since the best of those may be counterfeited or made by art and design, as may also books, manuscripts, and inscriptions, as all the learned are now sufficiently satisfied has often been actually

* For an able analysis of the views of Leibnitz, in his Protogœa, see Mr. Conybeare's Report to the Brit. Assco. on the Progress of Geological Science, 1832.

practised,' &c.; 'and though it must be granted that it is very difficult to read them (the records of nature) and *to raise a chronology out of them*, and to state the intervals of the time wherein such or such catastrophes and mutations have happened, yet it is not impossible.' *

Respecting the extinction of species, Hooke was aware that the fossil ammonites, nautili, and many other shells and fossil skeletons found in England were of different species from any then known; but he doubted whether the species had become extinct, observing that the knowledge of naturalists of all the marine species, especially those inhabiting the deep sea, was very defective. In some parts of his writing, however, he leans to the opinion that species had been lost; and in speculating on this subject, he even suggests that there might be some connection between the disappearance of certain kinds of animals and plants, and the changes wrought by earthquakes in former ages. Some species, he observes, with great sagacity, are '*peculiar to certain places*, and not to be found elsewhere. If, then, such a place had been swallowed up, it is not improbable but that those animate beings may have been destroyed with it; and this may be true both of aërial and aquatic animals: for those animated bodies, whether vegetables or animals, which were naturally nourished or refreshed by the air, would be destroyed by the water,' &c.† Turtles, he adds, and such large ammonites as are found in Portland, seem to have been the productions of hotter countries; and it is necessary to suppose that England once lay under the sea within the torrid zone! To explain this and similar phenomena, he indulges in a variety of speculations concerning changes in the position of the axis of the earth's rotation, 'a shifting of the earth's centre of gravity, analogous to the revolutions of the magnetic pole,' &c. None of these conjectures, however, are proposed dogmatically, but rather in the hope of promoting fresh enquiries and experiments.

In opposition to the prejudices of his age, we find him arguing against the idea that nature had formed fossil bodies 'for no other end than to play the mimic in the mineral

* Posth. Works, Lecture, Feb. 29, 1688.

† Posth. Works, p. 327.

kingdom;'—maintaining that figured stones were 'really the several bodies they represent, or the mouldings of them petrified,' and 'not as some have imagined, "a lusus naturæ," sporting herself in the needless formation of useless beings.'* He explained, with considerable clearness, the different modes in which organic substances may become lapidified; and, among other illustrations, he mentions some silicified palm-wood brought from Africa, on which M. de la Hire had read a memoir to the Royal Academy of France (June 1692), wherein he had pointed out, not only the tubes running the length of the trunk, but the roots at one extremity. De la Hire, says Hooke, also treated of certain trees found petrified in the 'river that passes by Bakan, in the kingdom of *Ava*, and which has for the space of ten leagues the virtue of petrifying wood.' It is an interesting fact that the silicified wood of the Irawadi should have attracted attention nearly two hundred years ago. Remarkable discoveries have been made there in later times (1827) of fossil animals and vegetables, by Mr. Crawfurd and Dr. Wallich.†

It was objected to Hooke, that his doctrine of the extinction of species derogated from the wisdom and power of the Omnipotent Creator; but he answered, that, as individuals die, there may be some termination to the duration of a species; and his opinions, he declared, were not repugnant to Holy Writ: for the Scriptures taught that our system was degenerating, and tending to its final dissolution; 'and as, when that shall happen, all the species will be lost, why not some at one time and some at another?' ‡

But his principal object was to account for the manner in which shells had been conveyed into the higher parts of 'the Alps, Apennines, and Pyrenean hills, and the interior of continents in general.' These and other appearances, he said, might have been brought about by earthquakes, 'which have turned plains into mountains, and mountains into plains, seas into land, and land into seas, made rivers where there

* Posth. Works, Lecture, Feb. 15, 1688.

† See Geol. Trans. vol. ii. part iii. p. 377, second series. De la Hire cites Father Duchatz in the second volume of 'Observations made in the Indies by the Jesuits.'

‡ Posth. Works, Lecture, May 29, 1689.

were none before, and swallowed up others that formerly were, &c. &c.; and which, since the creation of the world, have wrought many changes on the superficial parts of the earth, and have been the instruments of placing shells, bones, plants, fishes, and the like, in those places where, with much astonishment, we find them.'* This doctrine, it is true, had been laid down in terms almost equally explicit by Strabo, to explain the occurrence of fossil shells in the interior of continents, and to that geographer, and other writers of antiquity, Hooke frequently refers; but the revival and development of the system was an important step in the progress of modern science.

Hooke enumerated all the examples known to him of subterranean disturbance, from 'the sad catastrophe of Sodom and Gomorrah,' down to the Chilian earthquake of 1646. The elevating of the bottom of the sea, the sinking and submersion of the land, and most of the inequalities of the earth's surface, might, he said, be accounted for by the agency of these subterranean causes. He mentions that the coast near Naples *was raised during the eruption of Monte Nuovo*; and that, in 1591, land rose in the island of St. Michael, during an eruption: and although it would be more difficult, he says, to prove, he does not doubt but that there had been as many earthquakes in the parts of the earth under the ocean, as in the parts of the dry land; in confirmation of which, he mentions the immeasurable depth of the sea near some volcanos. To attest the extent of simultaneous subterranean movements, he refers to an earthquake in the West Indies, in the year 1690, where the space of earth raised, or 'struck upwards,' by the shock, exceeded, he affirms, the length of the Alps and Pyrenees.

Hooke's diluvial theory.—As Hooke declared the favourite hypothesis of the day, 'that marine fossil bodies were to be referred to Noah's flood,' to be wholly untenable, he appears to have felt himself called upon to substitute a diluvial theory of his own, and thus he became involved in countless difficulties and contradictions. 'During the great catastrophe,'

* Posth. Works, p. 312.

he said, 'there might have been a changing of that part which was before dry land into sea by sinking, and of that which was sea into dry land by raising, and marine bodies might have been buried in sediment beneath the ocean, in the interval between the creation and the deluge.'* Then follows a disquisition on the separation of the land from the waters, mentioned in Genesis; during which operation some places of the shell of the earth were forced outwards, and others pressed downwards or inwards, &c. His diluvial hypothesis very much resembled that of Steno, and was entirely opposed to the fundamental principles professed by him, that he would explain the former changes of the earth *in a more natural manner* than others had done. When, in despite of this declaration, he required a former 'crisis of nature,' and taught that earthquakes had become debilitated, and that the Alps, Andes, and other chains, had been lifted up in a few months, he was compelled to assume so rapid a rate of change, that his machinery appeared scarcely less extravagant than that of his most fanciful predecessors. For this reason, perhaps, his whole theory of earthquakes met with undeserved neglect.

Ray, 1692.—One of his contemporaries, the celebrated naturalist, Ray, participated in the same desire to explain geological phenomena by reference to causes less hypothetical than those usually resorted to.† In his essay on 'Chaos and Creation,' he proposed a system, agreeing in its outline, and in many of its details, with that of Hooke; but his knowledge of natural history enabled him to elucidate the subject with various original observations. Earthquakes, he suggested, might have been the second causes employed at the creation, in separating the land from the waters, and in gathering the waters together into one place. He mentions, like Hooke, the earthquake of 1646, which had violently shaken the Andes for some hundreds of leagues, and made many alterations therein. In assigning a cause for the general deluge, he

* Posth. Works, p. 410.

† Ray's Physico-theological Discourses were of somewhat later date than Hooke's great work on earthquakes. He speaks of Hooke as one 'whom for his learning and deep insight into the mysteries of nature he deservedly honoured.'—*On the Deluge*, chap. iv.

preferred a change in the earth's centre of gravity to the introduction of earthquakes. Some unknown cause, he said, might have forced the subterranean waters outwards, as was perhaps indicated by 'the breaking up of the fountains of the great deep.'

Ray was one of the first of our writers who enlarged upon the effects of running water upon the land, and of the encroachment of the sea upon the shores. So important did he consider the agency of these causes, that he saw in them an indication of the tendency of our system to its final dissolution; and he wondered why the earth did not proceed more rapidly towards a general submersion beneath the sea, when so much matter was carried down by rivers, or undermined in the sea-cliffs. We perceive clearly from his writings, that the gradual decline of our system, and its future consummation by fire, was held to be as necessary an article of faith by the orthodox, as was the recent origin of our planet. His discourses, like those of Hooke, are highly interesting, as attesting the familiar association in the minds of philosophers, in the age of Newton, of questions in physics and divinity. Ray gave an unequivocal proof of the sincerity of his mind, by sacrificing his preferment in the Church, rather than take an oath against the Covenanters, which he could not reconcile with his conscience. His reputation, moreover, in the scientific world placed him high above the temptation of courting popularity, by pandering to the physico-theological taste of his age. It is, therefore, curious to meet with so many citations from the Christian fathers and prophets in his essays on physical science—to find him in one page proceeding, by the strict rules of induction, to explain the former changes of the globe, and in the next gravely entertaining the question, whether the sun and stars, and the whole heavens, shall be annihilated, together with the earth, at the era of the grand conflagration.

Woodward, 1695.—Among the contemporaries of Hooke and Ray, Woodward, a professor of medicine, had acquired the most extensive information respecting the geological structure of the crust of the earth. He had examined many parts of the British strata with minute attention; and his

systematic collection of specimens, bequeathed to the University of Cambridge, and still preserved there as arranged by him, shows how far he had advanced in ascertaining the order of superposition. From the great number of facts collected by him, we might have expected his theoretical views to be more sound and enlarged than those of his contemporaries; but in his anxiety to accommodate all observed phenomena to the scriptural account of the Creation and Deluge, he arrived at most erroneous results. He conceived 'the whole terrestrial globe to have been taken to pieces and dissolved at the flood, and the strata to have settled down from this promiscuous mass as any earthy sediment from a fluid.' * In corroboration of these views he insisted upon the fact, that 'marine bodies are lodged in the strata according to the order of their gravity, the heavier shells in stone, the lighter in chalk, and so of the rest.' † Ray immediately exposed the unfounded nature of this assertion, remarking truly that fossil bodies 'are often mingled, heavy with light, in the same stratum;' and he even went so far as to say, that Woodward 'must have invented the phenomena for the sake of confirming his bold and strange hypothesis.' ‡

Burnet, 1680–1690.—At the same time Burnet published his 'Theory of the Earth.' § The title is most characteristic of the age,—'The Sacred Theory of the Earth; containing an Account of the Original of the Earth, and of all the general Changes which it hath already undergone, or is to undergo, till the Consummation of all things.' Even Milton had scarcely ventured in his poem to indulge his imagination so freely in painting scenes of the Creation and Deluge, Paradise and Chaos. He explained why the primeval earth enjoyed a perpetual spring before the flood; showed how the crust of the globe was fissured by 'the sun's rays,' so that it burst, and thus the diluvial waters were let loose from a supposed central abyss. Not satisfied with these themes, he derived from the books of the inspired writers, and even from heathen authorities, prophetic views of the

* Essay towards a Natural History of the Earth, 1695. Preface.

† Ibid.

‡ Consequences of the Deluge, p. 165.

§ First published in Latin between the years 1680 and 1690.

future revolutions of the globe, gave a most terrific description of the general conflagration, and proved that a new heaven and a new earth will rise out of a *second chaos*—after which will follow the blessed millennium.

The reader should be informed, that, according to the opinion of many respectable writers of that age, there was good scriptural ground for presuming that the garden bestowed upon our first parents was not on the earth itself, but above the clouds, in the middle region between our planet and the moon. Burnet approaches with becoming gravity the discussion of so important a topic. He was willing to concede that the geographical position of Paradise was not in Mesopotamia, yet he maintained that it was upon the earth, and in the southern hemisphere, near the equinoctial line. Butler selected this conceit as a fair mark for his satire, when, amongst the numerous accomplishments of Hudibras, he says,—

> He knew the seat of Paradise,
> Could tell in what degree it lies;
> And, as he was disposed, could prove it
> Below the moon, or else above it.

Yet the same monarch, who is said never to have slept without Butler's poem under his pillow, was so great an admirer and patron of Burnet's book, that he ordered it to be translated from the Latin into English. The style of the 'Sacred Theory' was eloquent, and the book displayed powers of invention of no ordinary stamp. In was, in fact, a fine historical romance, as Buffon afterwards declared: but it was treated as a work of profound science in the time of its author, and was panegyrised by Addison in a Latin ode, while Steele praised it in the 'Spectator.'

Whiston, 1696.—Another production of the same school, and equally characteristic of the time, was that of Whiston, entitled, 'A New Theory of the Earth; wherein the Creation of the World in Six Days, the Universal Deluge, and the General Conflagration, as laid down in the Holy Scriptures, are shown to be perfectly agreeable to Reason and Philosophy.' He was at first a follower of Burnet; but his faith in the infallibility of that writer was shaken by the declared

opinion of Newton, that there was every presumption in astronomy against any former change in the inclination of the earth's axis. This was a leading dogma in Burnet's system, though not original, for it was borrowed from an Italian, Alessandro degli Alessandri, who had suggested it in the beginning of the fifteenth century, to account for the former occupation of the present continents by the sea. La Place has since strengthened the arguments of Newton, against the probability of any former revolution of this kind.

The remarkable comet of 1680 was fresh in the memory of every one when Whiston first began his cosmological studies; and the principal novelty of his speculations consisted in attributing the deluge to the near approach to the earth of one of these erratic bodies, and the condensation of the vapour of its tail into water. Having ascribed an increase of the waters to this source, he adopted Woodward's theory, supposing all stratified deposits to have resulted from the 'chaotic sediment of the flood.' Whiston was one of the first who ventured to propose that the text of Genesis should be interpreted differently from its ordinary acceptation, so that the doctrine of the earth having existed long previous to the creation of man might be no longer regarded as unorthodox. He had the art to throw an air of plausibility over the most improbable parts of his theory, and seemed to be proceeding in the most sober manner, and, by the aid of mathematical demonstration, to the establishment of his various propositions. Locke pronounced a panegyric on his theory, commending him for having explained so many wonderful and before inexplicable things. His book, as well as Burnet's, was attacked and refuted by Keill.*

Hutchinson, 1724.—John Hutchinson, who had been employed by Woodward in making his collection of fossils, published afterwards, in 1724, the first part of his 'Moses's Principia,' wherein he ridiculed Woodward's hypothesis. He and his numerous followers were accustomed to declaim loudly against human learning; and they maintained that the Hebrew Scriptures, when rightly translated, comprised a

* An Examination of Dr. Burnet's Theory, &c. 2d ed. 1734.

perfect system of natural philosophy, for which reason they objected to the Newtonian theory of gravitation.

Celsius.—Andrea Celsius, the Swedish astronomer, published about this time his remarks on the gradual diminution and sinking of the waters in the Baltic, to which I shall have occasion to advert more particularly in the sequel (Ch. 31).

Scheuchzer, 1708.—In Germany, in the meantime, Scheuchzer published his 'Complaint and Vindication of the Fishes' (1708), 'Piscium Querelæ et Vindiciæ,' a work of zoological merit, in which he gave some good plates and descriptions of fossil fish. Among other conclusions he laboured to prove that the earth had been remodelled at the deluge. Pluche, also, in 1732, wrote to the same effect; while Holbach, in 1753, after considering the various attempts to refer all the ancient formations to the flood of Noah, exposed the inadequacy of this cause.

Italian Geologists—Vallisneri, 1721.—I return with pleasure to the geologists of Italy, who preceded, as has been already shown, the naturalists of other countries in their investigations into the ancient history of the earth, and who still maintained a decided pre-eminence. They refuted and ridiculed the physico-theological systems of Burnet, Whiston, and Woodward; while Vallisneri,* in his comments on the Woodwardian theory, remarked how much the interests of religion, as well as those of sound philosophy, had suffered by perpetually mixing up the sacred writings with questions in physical science. The works of this author were rich in original observations. He attempted the first general sketch of the marine deposits of Italy, their geographical extent, and most characteristic organic remains. In his treatise 'On the Origin of Springs,' he explained their dependence on the order, and often on the dislocations, of the strata, and reasoned philosophically against the opinions of those who regarded the disordered state of the earth's crust as exhibiting signs of the wrath of God for the sins of man. He found himself under the necessity of contending, in his preliminary chapter, against St. Jerome, and four other principal

* Dei Corpi Marini. Lettere critiche, &c. 1721.

interpreters of Scripture, besides several professors of divinity, 'that springs did not flow by subterranean siphons and cavities from the sea upwards, losing their saltness in the passage,' for this theory had been made to rest on the infallible testimony of Holy Writ.

Although reluctant to generalise on the rich materials accumulated in his travels, Vallisneri had been so much struck with the remarkable continuity of the more recent marine strata, from one end of Italy to the other, that he came to the conclusion that the ocean formerly extended over the whole earth, and after abiding there for a long time, had gradually subsided. This opinion, however untenable, was a great step beyond Woodward's diluvian hypothesis, against which Vallisneri, and after him all the Tuscan geologists, uniformly contended, while it was warmly supported by the members of the Institute of Bologna.*

Among others of that day, Spada, a priest of Grezzana, in 1737, wrote to prove that the petrified marine bodies near Verona were not diluvian.† Mattani drew a similar inference from the shells of Volterra and other places: while Costantini, on the other hand, whose observations on the valley of the Brenta and other districts were not without value, undertook to vindicate the truth of the deluge, as also to prove that Italy had been peopled by the descendants of Japhet.‡

Moro, 1740.—Lazzaro Moro, in his work (published in 1740) 'On the Marine Bodies which are found in the Mountains,'§ attempted to apply the theory of earthquakes, and changes of level in the earth's crust, as expounded by Strabo, Pliny, and other ancient authors, with whom he was familiar, to the geological phenomena described by Vallisneri.‖ His attention was awakened to the elevating power of subterranean forces by a remarkable phenomenon

* Brocchi, p. 28.

† Ibid. p. 33.

‡ Ibid.

§ Sui Crostacei ed altri Corpi Marini che si trovano sui Monti.

‖ Moro does not cite the works of Hooke and Ray: and although so many of his views were in accordance with theirs, he was probably ignorant of their writings, for they had not been translated. As he always refers to the Latin edition of Burnet, and a French translation of Woodward, we may presume that he did not read English.

which happened in his own time, and which had also been noticed by Vallisneri in his letters. A new island rose in 1707 from deep water in the Gulf of Santorin in the Mediterranean, during continued shocks of an earthquake, and, increasing rapidly in size, grew in less than a month to be half a mile in circumference, and about twenty-five feet above high-water mark.* It was soon afterwards covered by volcanic ejections, but, when first examined, it was found to be a white rock, bearing on its surface living oysters and crustacea. In order to ridicule the various theories then in vogue, Moro ingeniously supposes the arrival on this new island of a party of naturalists ignorant of its recent origin. One immediately points to the marine shells, as proofs of the universal deluge; another argues that they demonstrate the former residence of the sea upon the mountains; a third dismisses them as mere *sports of nature*; while a fourth affirms, that they were born and nourished within the rock in ancient caverns, into which salt water had been raised in the shape of vapour by the action of subterranean heat.

Moro pointed with great judgment to the *faults* and dislocations of the strata described by Vallisneri, in the Alps and other chains, in confirmation of his doctrine, that the continents had been heaved up by subterranean movements. He objected, on solid grounds, to the hypothesis of Burnet and of Woodward; yet he ventured so far to disregard the protest of Vallisneri, as to undertake the adaptation of every part of his own system to the Mosaic account of the creation. On the third day, he said, the globe was everywhere covered to the same depth by fresh water; and when it pleased the Supreme Being that the dry land should appear, volcanic explosions broke up the smooth and regular surface of the earth composed of primary rocks. These rose in mountain masses above the waves, and allowed melted metals and salts to ascend through fissures. The sea gradually acquired its saltness from volcanic exhalations, and, while it became more circumscribed in area, increased in depth. Sand and ashes ejected by volcanos

* For an account of a similar eruption in the Gulf of Santorin in 1866, see Principles of Geology, vol. ii. p. 69, 10th ed. 1868.

were regularly disposed along the bottom of the ocean, and formed the secondary strata, which in their turn were lifted up by earthquakes. We need not follow this author in tracing the progress of the creation of vegetables and animals on the other days of creation; but, upon the whole, it may be remarked, that few of the old cosmological theories had been conceived with so little violation of known analogies.

Generelli's illustrations of Moro, 1749.—The style of Moro was extremely prolix, and, like Hutton, who, at a later period, advanced many of the same views, he stood in need of an illustrator. The Scotch geologist was hardly more fortunate in the advocacy of Playfair, than was Moro in numbering amongst his admirers Cirillo Generelli, who, nine years afterwards, delivered at a sitting of Academicians at Cremona a spirited exposition of his theory. This learned Carmelite friar does not pretend to have been an original observer, but he had studied sufficiently to enable him to confirm the opinions of Moro by arguments from other writers; and the selection of the doctrines then best established is so judicious, that a brief abstract of them cannot fail to be acceptable, as illustrating the state of geology in Europe, and in Italy in particular, before the middle of the last century.

The bowels of the earth, says he, have carefully preserved the memorials of past events, and this truth the marine productions so frequent in the hills attest. From the reflections of Lazzaro Moro, we may assure ourselves that these are the effects of earthquakes in past times, which have changed vast spaces of sea into terra firma, and inhabited lands into seas. In this more than in any other department of physics, are observations and experiments indispensable, and we must diligently consider facts. The land is known, wherever we make excavations, to be composed of different strata or soils placed one above the other, some of sand, some of rock, some of chalk, others of marl, coal, pumice, gypsum, lime, and the rest. These ingredients are sometimes pure, and sometimes confusedly intermixed. Within are often imprisoned different marine fishes, like dried

mummies, and more frequently shells, crustacea, corals, plants, &c., not only in Italy, but in France, Germany, England, Africa, Asia, and America;—sometimes in the lowest, sometimes in the loftiest beds of the earth, some upon the mountains, some in deep mines, others near the sea, and others hundreds of miles distant from it. Woodward conjectured that these marine bodies might be found everywhere; but there are rocks in which none of them occur, as is sufficiently attested by Vallisneri and Marsilli. The remains of fossil animals consist chiefly of their more solid parts, and the most rocky strata must have been soft when such exuviæ were enclosed in them. Vegetable productions are found in different states of maturity, indicating that they were imbedded in different seasons. Elephants, elks, and other terrestrial quadrupeds, have been found in England and elsewhere, in superficial strata, never covered by the sea. Alternations are rare, yet not without example, of marine strata, with those which contain marshy and terrestrial productions. Marine animals are arranged in the subterraneous beds with admirable order, in distinct groups, oysters here, dentalia or corals there, &c., as now, according to Marsilli,* on the shores of the Adriatic. We must abandon the doctrine, once so popular, which denies that organised fossils were derived from living beings, and we cannot account for their present position by the ancient theory of Strabo, nor by that of Leibnitz, nor by the universal deluge, as explained by Woodward and others: 'nor is it reasonable to call the Deity capriciously upon the stage, and to make him work miracles for the sake of confirming our preconceived hypothesis.'—'I hold in utter abomination, most learned Academicians! those systems which are built with their foundations in the air, and cannot be propped up without a miracle; and I undertake, with the assistance of Moro, to explain to you how these marine animals were transported into the mountains by natural causes.'†

A brief abstract then follows of Moro's theory, by which,

* Saggio fisico intorno alla Storia del Mare, part i. p. 24.

† 'Abbomino al sommo qualsivoglia sistema, che sia di pianta fabbricato in aria; massime quando è tale, che non possa sostenersi senza un miracolo,' &c. —De' Crostacei e di altre Produz. del Mare, &c. 1749.

says Generelli, we may explain all the phenomena, as Vallisneri so ardently desired, 'without violence, without fictions, without hypothesis, without miracles'—'Senza violenze, senza finzioni, senza supposti, senza miracoli.' The Carmelite then proceeds to struggle against an obvious objection to Moro's system, considered as a method of explaining the revolutions of the earth, *naturally*. If earthquakes have been the agents of such mighty changes, how does it happen that their effects since the times of history have been so inconsiderable? This same difficulty had, as we have seen, presented itself to Hooke, half a century before, and forced him to resort to a former 'crisis of nature:' but Generelli defended his position by showing how numerous were the accounts of eruptions and earthquakes, of new islands, and of elevations and subsidences of land, and yet how much greater a number of like events must have been unattested and unrecorded during the last six thousand years. He also appealed to Vallisneri as an authority to prove that the mineral masses containing shells bore, upon the whole, but a small proportion to those rocks which were destitute of organic remains; and the latter, says the learned monk, might have been created as they now exist, *in the beginning*.

Generelli then describes the continual waste of mountains and continents, by the action of rivers and torrents, and concludes with these eloquent and original observations:—'Is it possible that this waste should have continued for six thousand, and *perhaps* a greater number of years, and that the mountains should remain so great, unless their ruins have been repaired? Is it credible that the Author of Nature should have founded the world upon such laws, as that the dry land should for ever be growing smaller, and at last become wholly submerged beneath the waters? Is it credible that, amid so many created things, the mountains alone should daily diminish in number and bulk, without there being any repair of their losses? This would be contrary to that order of Providence which is seen to reign in all other things in the universe. Wherefore I deem it just to conclude, that the same cause which, in the beginning of time, raised mountains from the abyss, has down

to the present day continued to produce others, in order to restore from time to time the losses of all such as sink down in different places, or are rent asunder, or in other ways suffer disintegration. If this be admitted, we can easily understand why there should now be found upon many mountains so great a number of crustacea and other marine animals.'

In the above extract, I have not merely enumerated the opinions and facts which are confirmed by recent observation, suppressing all that has since proved to be erroneous, but have given a faithful abridgment of the entire treatise, with the omission only of Moro's hypothesis, which Generelli adopted, with all its faults and excellences. The reader will therefore remark, that although this admirable essay embraces so large a portion of the principal objects of geological research, it makes no allusion to the extinction of certain classes of animals; and it is evident that no opinions on this head had, at that time, gained a firm footing in Italy. That Lister and other English naturalists should long before have declared in favour of the loss of species, while Scilla and most of his countrymen hesitated, was perhaps natural, since the Italian museums were filled with fossil shells belonging to species of which a great portion did actually exist in the Mediterranean; whereas the English collectors could obtain no recent species from such of their own strata as were then explored.

The weakest point in Moro's system consisted in deriving *all* the stratified rocks from volcanic ejections; an absurdity which his opponents took care to expose, especially Vito Amici.* Moro seems to have been misled by his anxious desire to represent the formation of secondary rocks as having occupied an extremely short period, while at the same time he wished to employ known agents in nature. To imagine torrents, rivers, currents, partial floods, and all the operations of moving water, to have gone on exerting an energy many thousand times greater than at present, would have appeared preposterous and incredible, and would have required a

* Sui Testacei della Sicilia.

hundred violent hypotheses; but we are so unacquainted with the true sources of subterranean disturbances, that their former violence may in theory be multiplied indefinitely, without its being possible to prove the same manifest contradiction or absurdity in the conjecture. For this reason, perhaps, Moro preferred to derive the materials of the strata from volcanic ejections, rather than from transportation by running water.

Marsilli.—Marsilli, whose work is alluded to by Generelli, had been prompted to institute enquiries into the bed of the Adriatic, by discovering, in the territory of Parma, (what Spada had observed near Verona, and Schiavo in Sicily,) that fossil shells were not scattered through the rocks at random, but disposed in regular order, according to certain genera and species.

Vitaliano Donati, 1750.—With a view of throwing further light upon these questions, Donati, in 1750, undertook a more extensive investigation of the Adriatic, and discovered, by numerous soundings, that deposits of sand, marl, and tufaceous incrustations, most strictly analogous to those of the Subapennine hills, were in the act of accumulating there. He ascertained that there were no shells in some of the submarine tracts, while in other places they lived together in families, particularly the genera Arca, Pecten, Venus, Murex, and some others. He also states that in divers localities he found a mass composed of corals, shells, and crustaceous bodies of different species, confusedly blended with earth, sand, and gravel. At the depth of a foot or more, the organic substances were entirely petrified and reduced to marble; at less than a foot from the surface, they approached nearer to their natural state; while at the surface they were alive, or, if dead, in a good state of preservation.

Baldassari.—A contemporary naturalist, Baldassari, had shown that the organic remains in the tertiary marls of the Siennese territory were grouped in families, in a manner precisely similar to that above alluded to by Donati.

Buffon, 1749.—Buffon first made known his theoretical views concerning the former changes of the earth, in his 'Natural History,' published in 1749. He adopted the theory

of an original volcanic nucleus, together with the universal ocean of Leibnitz. By this aqueous envelope the highest mountains were once covered. Marine currents then acted violently, and formed horizontal strata, by washing away solid matter in some parts, and depositing it in others; they also excavated deep submarine valleys. The level of the ocean was then depressed by the entrance of a part of its waters into subterranean caverns, and thus some land was left dry. Buffon seems not to have profited, like Leibnitz and Moro, by the observations of Steno, or he could not have imagined that the strata were generally horizontal, and that those which contained organic remains had never been disturbed since the era of their formation. He was conscious of the great power annually exerted by rivers and marine currents in transporting earthy materials to lower levels, and he even contemplated the period when they would destroy all the present continents. Although in geology he was not an original observer, his genius enabled him to render his hypothesis attractive; and by the eloquence of his style, and the boldness of his speculations, he awakened curiosity, and provoked a spirit of enquiry among his countrymen.

Soon after the publication of his 'Natural History,' in which was included his 'Theory of the Earth,' he received an official letter (dated January 1751) from the Sorbonne, or Faculty of Theology in Paris, informing him that fourteen propositions in his works 'were reprehensible, and contrary to the creed of the church.' The first of these obnoxious passages, and the only one relating to geology, was as follows:—'The waters of the sea have produced the mountains and valleys of the land—the waters of the heavens, reducing all to a level, will at last deliver the whole land over to the sea, and the sea successively prevailing over the land, will leave dry new continents like those which we inhabit.' Buffon was invited by the College, in very courteous terms, to send in an explanation, or rather a recantation of his unorthodox opinions. To this he submitted; and a general assembly of the Faculty having approved of his 'Declaration,' he was required to publish it in his next work. The document begins with these words:—'I declare that I

had no intention to contradict the text of Scripture; that I believe most firmly all therein related about the creation, both as to order of time and matter of fact; *I abandon everything in my book respecting the formation of the earth,* and, generally, all which may be contrary to the narration of Moses.' *

The grand principle which Buffon was called upon to renounce was simply this,—'that the present mountains and valleys of the earth are due to secondary causes, and that the same causes will in time destroy all the continents, hills, and valleys, and reproduce others like them.' Now, whatever may be the defects of many of his views, it is no longer controverted that the present continents are of secondary origin. The doctrine is as firmly established as the earth's rotation on its axis; and that the land now elevated above the level of the sea will not endure for ever, is an opinion which gains ground daily, in proportion as we enlarge our experience of the changes now in progress.

Targioni, 1751.—Targioni, in his voluminous 'Travels in Tuscany, 1751 and 1754,' laboured to fill up the sketch of the geology of that region left by Steno sixty years before. Notwithstanding a want of arrangement and condensation in his memoirs, they contained a rich store of faithful observations. He has not indulged in many general views, but in regard to the origin of valleys, he was opposed to the theory of Buffon, who attributed them principally to submarine currents. The Tuscan naturalist laboured to show that both the larger and smaller valleys of the Apennines were excavated by rivers and floods, caused by the bursting of the barriers of lakes, after the retreat of the ocean. He also maintained that the elephants and other quadrupeds, so frequent in the lacustrine and alluvial deposits of Italy, had inhabited that peninsula; and had not been transported thither, as some had conceived, by Hannibal or the Romans, nor by what they were pleased to term 'a catastrophe of nature.'

Lehman, 1756.—In the year 1756 the treatise of Lehman,

* Hist. Nat. tom. v. éd. de l'Imp. Royale. Paris, 1769.

a German mineralogist, and director of the Prussian mines, appeared, who divided mountains into three classes; the first, those formed with the world, and prior to the creation of animals, and which contained no fragments of other rocks; the second class, those which resulted from the partial destruction of the primary rocks by a general revolution; and a third class, resulting from local revolutions, and in part from the deluge of Noah.

A French translation of this work appeared in 1759, in the preface of which, the translator displays very enlightened views respecting the operations of earthquakes, as well as of aqueous causes.*

Gesner, 1758.—In this year Gesner, the botanist of Zurich, published an excellent treatise on petrifactions, and the changes of the earth which they testify.† After a detailed enumeration of the various classes of fossils of the animal and vegetable kingdoms, and remarks on the different states in which they are found petrified, he considers the geological phenomena connected with them; observing, that some, like those of Œningen, resembled the testacea, fish, and plants indigenous in the neighbouring region; ‡ while some, such as ammonites, gryphites, belemnites, and other shells, are either of unknown species, or found only in the Indian or other distant seas. In order to elucidate the structure of the earth, he gives sections, from Verenius, Buffon, and others, obtained in digging wells; distinguishes between horizontal and inclined strata; and, in speculating on the causes of these appearances, mentions Donati's examination of the bed of the Adriatic; the filling up of lakes and seas by sediment; the imbedding of shells, now in progress; and many known effects of earthquakes, such as the sinking down of districts, or the heaving up of the bed of the sea, so as to form new islands, and lay dry strata containing petrifactions. The ocean, he says, deserts its shores in many countries, as on the borders of the Baltic; but the rate of recession has been so slow in the last 2,000 years, that to allow the Apennines,

* Essai d'une Hist. nat. des Couches de la Terre. 1759.

† John Gesner published at Leyden, in Latin.

‡ Part. ii. chap. 9.

whose summits are filled with marine shells, to emerge to their present height, would have required about 80,000 years,—a lapse of time ten times greater, or more, than the age of the universe. We must therefore refer the phenomenon to the command of the Deity, related by Moses, that 'the waters should be gathered together in one place, and the dry land appear.' Gesner adopted the views of Leibnitz, to account for the retreat of the primeval ocean: his essay displays much erudition; and the opinions of preceding writers of Italy, Germany, and England, are commented upon with fairness and discrimination.

Arduino, 1759.—In the year following, Arduino,* in his memoirs on the mountains of Padua, Vicenza, and Verona, deduced, from original observations, the distinction of rocks into primary, secondary, and tertiary, and showed that in those districts there had been a succession of submarine volcanic eruptions.

Michell, 1760.—In the following year (1760) the Rev. John Michell, Woodwardian Professor of Mineralogy at Cambridge, published in the Philosophical Transactions, an Essay on the Cause and Phenomena of Earthquakes.† His attention had been drawn to this subject by the great earthquake of Lisbon in 1755. He advanced many original and philosophical views respecting the propagation of subterranean movements, and the caverns and fissures wherein steam might be generated. In order to point out the application of his theory to the structure of the globe, he was led to describe the arrangement and disturbance of the strata, their usual horizontality in low countries, and their contortions and fractured state in the neighbourhood of mountain chains. He also explained, with surprising accuracy, the relations of the central ridges of older rocks to the 'long narrow slips of earth, stones, and minerals,' which are parallel to these ridges. In his generalisations, derived in great part from his own observations on the geological structure of Yorkshire, he anticipated many of the views

* Giornale de' Criselini. 1759

† See a Sketch of the History of English Geology, by Dr. Fitton, in Edinb. Rev. Feb. 1818, re-edited Lond. and Edinb. Phil. Mag. vol. i. and ii. 1832-33.

more fully developed by later naturalists. Some of Michell's observations anticipate in so remarkable a manner the theories established forty years afterwards, that his writings would probably have formed an era in the science, if his researches had been uninterrupted. He held, however, his professorship only eight years, when his career was suddenly cut short by preferment to a benefice. From that time he appears to have been engaged in his clerical duties, and to have entirely discontinued his scientific pursuits.*

Catcott, 1761.—Michell's papers were entirely free from all physico-theological disquisitions, but some of his contemporaries were still earnestly engaged in defending or impugning the Woodwardian hypothesis. We find many of these writings referred to by Catcott, a Hutchinsonian, who published a 'Treatise on the Deluge' in 1761. He laboured particularly to refute an explanation offered by his contemporary, Bishop Clayton, of the Mosaic writings. That prelate had declared that the deluge 'could not be literally true, save in respect to that part where Noah lived before the flood.' Catcott insisted on the universality of the deluge, and referred to traditions of inundations mentioned by ancient writers, or by travellers, in the East Indies, China, South America, and other countries. This part of his book is valuable, although it is not easy to see what bearing the traditions have, if admitted to be authentic, on the Bishop's argument, since no evidence is adduced to prove that the catastrophes were contemporaneous events, while some of them are expressly represented by ancient authors to have occurred in succession.

Fortis—Odoardi, 1761.—The doctrines of Arduino, above adverted to, were afterwards confirmed by Fortis and Desmarest, in their travels in the same country; and they, as well as Baldassari, laboured to complete the history of the

* The abrupt suspension of Michell's scientific career exemplified the disadvantageous working of a system in full force at Oxford and Cambridge in the last century, where the chairs of mathematics, natural philosophy, chemistry, botany, astronomy, geology, mineralogy, and others, being frequently filled by clergymen, the reward of success disqualified them, if they conscientiously discharged their new duties, from farther advancing the cause of science, and that, too, at the moment when their labours would naturally bear the richest fruits.

Subapennine strata. In the work of Odoardi,* there was also a clear argument in favour of the distinct ages of the older Apennine strata, and the Subapennine formations of more recent origin. He pointed out that the strata of these two groups were *unconformable*, and must have been the deposits of different seas at distant periods of time.

Raspe, 1763.—A history of the new islands by Raspe, an Hanoverian, appeared in 1763, in Latin.† In this work, all the authentic accounts of earthquakes which had produced permanent changes on the solid parts of the earth were collected together and examined with judicious criticism. The best systems which had been proposed concerning the ancient history of the globe, both by ancient and modern writers, are reviewed; and the merits and defects of the doctrines of Hooke, Ray, Moro, Buffon, and others, fairly estimated. Great admiration is expressed for the hypothesis of Hooke, and his explanation of the origin of the strata is shown to have been more correct than Moro's, while their theory of the effects of earthquakes was the same. Raspe had not seen Michell's memoirs, and his views concerning the geological structure of the earth were perhaps less enlarged; yet he was able to add many additional arguments in favour of Hooke's theory, and to render it, as he said, a nearer approach to what Hooke would have written had he lived in later times. As to the periods wherein all the earthquakes happened, to which we owe the elevation of various parts of our continents and islands, Raspe says he pretends not to assign their duration, still less to defend Hooke's suggestion, that the convulsions almost all took place during the deluge of Noah. He adverts to the apparent indications of the former tropical heat of the climate of Europe, and the changes in the species of animals and plants, as among the most obscure and difficult problems in geology. In regard to the islands raised from the sea, within the times of history or tradition, he declares that some of them were

* Sui Corpi Marini del Feltrino. 1761.

† De Novis e Mari Natis Insulis. Raspe was also the editor of the 'Philosophical Works of Leibnitz. Amst. et Leipzig, 1765;' also author of 'Tassie's Gems,' and 'Baron Munchausen's Travels.'

composed of strata containing organic remains, and that they were not, as Buffon had asserted, made of mere volcanic matter. His work concludes with an eloquent exhortation to naturalists to examine the isles which rose, in 1707, in the Grecian Archipelago, and, in 1720, in the Azores, and not to neglect such splendid opportunities of studying nature 'in the act of parturition.' That Hooke's writings should have been neglected for more than half a century, was matter of astonishment to Raspe; but it is still more wonderful that his own luminous exposition of that theory should, for more than another half-century, have excited so little interest.

Fuchsel, 1762–1773.—Fuchsel, a German physician, published, in 1762, a geological description of the country between the Thuringerwald and the Hartz, and a memoir on the environs of Rudolstadt;* and afterwards, in 1773, a theoretical work on the ancient history of the earth and of man.† He had evidently advanced considerably beyond his predecessor Lehman, and was aware of the distinctness, both as to position and fossil contents, of several groups of strata of different ages, corresponding to the secondary formations now recognised by geologists in various parts of Germany. He supposed the European continents to have remained covered by the sea until the formation of the marine strata called in Germany 'muschelkalk,' at the same time that the terrestrial plants of many European deposits, attested the existence of dry land which bordered the ancient sea; land which, therefore, must have occupied the place of the present ocean. This pre-existing continent had been *gradually* swallowed up by the sea, different parts having subsided in succession into subterranean caverns. All the sedimentary strata were originally horizontal, and their present state of derangement must be referred to subsequent oscillations of the ground.

As there were plants and animals in the ancient periods, so also there must have been men, but they did not all

* Acta Academiæ Electoralis Maguntinæ, vol. ii. Erfurt.

† This account of Fuchsel is derived from an excellent analysis of his memoirs by M. Keferstein. Journ. de Géologie, tom. ii. Oct. 1830.

descend from one pair, but were created at various points on the earth's surface; and the number of these distinct birth-places was as great as are the original languages of nations.

In the writings of Fuchsel we see a strong desire manifested to explain geological phenomena as far as possible by reference to the agency of known causes; and although some of his speculations were fanciful, his views coincide much more nearly with those now generally adopted, than the theories afterwards promulgated by Werner and his followers.

Brander, 1766.—Gustavus Brander published, in 1766, his 'Fossilia Hantoniensia,' containing excellent figures of fossil shells from the Eocene marine strata of Hampshire. 'Various opinions,' he says in the preface, 'had been entertained concerning the time when and how these bodies became deposited. Some there are who conceive that it might have been effected in a wonderful length of time by a gradual changing and shifting of the sea,' &c. But the most common cause assigned is that of 'the deluge.' This conjecture, he says, even if the universality of the flood be not called in question, is purely hypothetical. In his opinion, fossil animals and testacea were, for the most part, of unknown species; and of such as were known, the living analogues now belonged to southern latitudes.

Soldani, 1780.—Soldani applied successfully his knowledge of zoology to illustrate the history of stratified masses. He explained that microscopic testacea and zoophytes inhabited the depths of the Mediterranean; and that the fossil species were, in like manner, found in those deposits wherein the fineness of their particles, and the absence of pebbles, implied that they were accumulated in a deep sea, or far from shore. This author first remarked the alternation of marine and freshwater strata in the Paris basin.*

Fortis—Testa, 1793.—A lively controversy arose between Fortis and another Italian naturalist, Testa, concerning the fish of Monte Bolca, in 1793. Their letters,† written with great spirit and elegance, show that they were aware that a

* Saggio orittografico, &c. 1780, and other Works.

† Lett. sui Pesci Fossili di Bolca. Milan, 1793.

large proportion of the Subapennine shells were identical with living species, and some of them with species now living in the torrid zone. Fortis proposed a somewhat fanciful conjecture, that when the volcanos of the Vicentin were burning, the waters of the Adriatic had a higher temperature; and in this manner, he said, the shells of warmer regions may once have flourished there. But Testa was disposed to think that these species of testacea were still common to their own and to equatorial seas: for many, he said, once supposed to be confined to hotter regions, had been afterwards discovered in the Mediterranean.

Cortesi—Spallanzani—Wallerius—Whitehurst, 1775-1798. —While these Italian naturalists, together with Cortesi and Spallanzani, were busily engaged in pointing out the analogy between the deposits of modern and ancient seas, and the habits and arrangements of their organic inhabitants, and while some progress was making, in the same country, in investigating the ancient and modern volcanic rocks, some of the most original observers among the English and German writers, Whitehurst* and Wallerius, were wasting their strength in contending, according to the old Woodwardian hypothesis, that all the strata were formed by Noah's deluge. But Whitehurst's description of the rocks of Derbyshire was most faithful; and he atoned for false theoretical views by providing data for their refutation.

Pallas—Saussure, 1793-1799.—Towards the close of the eighteenth century, the idea of dividing the mineral masses on our globe into separate groups, and studying their relations, began to be generally diffused. Pallas and Saussure were among the most celebrated whose labours contributed to this end. After an attentive examination of the two great mountain-chains of Siberia, Pallas announced the result, that the granite rocks were in the middle, the schistose at their sides, and the limestones again on the outside of these; and this he conceived would prove a general law in the formation of all chains composed chiefly of primary rocks.†

In his 'Travels in Russia,' in 1793 and 1794, he made

* Inquiry into the Original State and Formation of the Earth. 1778.

† Observ. on the Formation of Mountains. Act. Pétrop. ann. 1778, part i.

many geological observations on the recent strata near the Wolga and the Caspian, and adduced proofs of the greater extent of the latter sea at no distant era in the earth's history. His memoir on the fossil bones of Siberia attracted attention to some of the most remarkable phenomena in geology. He stated that he had found a rhinoceros entire in the frozen soil, with its skin and flesh: an elephant, found afterwards in a mass of ice on the shore of the North Sea, removed all doubt as to the credibility of so wonderful a discovery.*

The subjects relating to natural history which engaged the attention of Pallas, were too multifarious to admit of his devoting a large share of his labours exclusively to geology. Saussure, on the other hand, employed the chief portion of his time in studying the structure of the Alps and Jura, and he provided valuable data for those who followed him. He did not pretend to deduce any general system from his numerous observations; and the few theoretical opinions which escaped from him, seem, like those of Pallas, to have been chiefly derived from the cosmological speculations of preceding writers.

* Nov. comm. Pétr. XVII. Cuvier, Éloge de Pallas.

CHAPTER IV.

HISTORY OF THE PROGRESS OF GEOLOGY—*continued.*

WERNER'S APPLICATION OF GEOLOGY TO THE ART OF MINING—EXCURSIVE CHARACTER OF HIS LECTURES—ENTHUSIASM OF HIS PUPILS—HIS AUTHORITY—HIS THEORETICAL ERRORS—DESMAREST'S MAP AND DESCRIPTION OF AUVERGNE—CONTROVERSY BETWEEN THE VULCANISTS AND NEPTUNISTS—INTEMPERANCE OF THE RIVAL SECTS—HUTTON'S THEORY OF THE EARTH—HIS DISCOVERY OF GRANITE VEINS—ORIGINALITY OF HIS VIEWS—WHY OPPOSED—PLAYFAIR'S ILLUSTRATIONS—INFLUENCE OF VOLTAIRE'S WRITINGS ON GEOLOGY—IMPUTATIONS CAST ON THE HUTTONIANS BY WILLIAMS, KIRWAN, AND DE LUC—SMITH'S MAP OF ENGLAND—GEOLOGICAL SOCIETY OF LONDON—PROGRESS OF THE SCIENCES IN FRANCE—GROWING IMPORTANCE OF THE STUDY OF ORGANIC REMAINS.

Werner.—The art of mining had long been taught in France, Germany, and Hungary, in scientific institutions established for that purpose, where mineralogy has always been a principal branch of instruction.

Werner was named, in 1775, professor of that science in the 'School of Mines,' at Freyberg, in Saxony. He directed his attention not merely to the composition and external characters of minerals, but also to what he termed 'geognosy,' or the natural position of minerals in particular rocks, together with the grouping of those rocks, their geographical distribution, and various relations. The phenomena observed in the structure of the globe had hitherto served for little else than to furnish interesting topics for philosophical discussion: but when Werner pointed out their application to the practical purposes of mining, they were instantly regarded by a large class of men as an essential part of their professional education, and from that time the science was cultivated in Europe more ardently and systematically. Werner's mind was at once imaginative and richly stored with miscellaneous knowledge. He associated every thing

with his favourite science, and in his excursive lectures he pointed out all the economical uses of minerals, and their application to medicine: the influence of the mineral composition of rocks upon the soil, and of the soil upon the resources, wealth, and civilisation of man. The vast sandy plains of Tartary and Africa, he would say, retained their inhabitants in the shape of wandering shepherds; the granitic mountains and the low calcareous and alluvial plains gave rise to different manners, degrees of wealth, and intelligence. The history even of languages, and the migrations of tribes, had been determined by the direction of particular strata. The qualities of certain stones used in building would lead him to descant on the architecture of different ages and nations; and the physical geography of a country frequently invited him to treat of military tactics. The charm of his manners and his eloquence kindled enthusiasm in the minds of his pupils; and many, who had intended at first only to acquire a slight knowledge of mineralogy, when they had once heard him, devoted themselves to it as the business of their lives. In a few years, a small school of mines, before unheard of in Europe, was raised to the rank of a great university; and men already distinguished in science studied the German language, and came from the most distant countries to hear the great oracle of geology.*

Werner had a great antipathy to the mechanical labour of writing, and, with the exception of a valuable treatise on metalliferous veins, he could never be persuaded to pen more than a few brief memoirs, and those containing no development of his general views. Although the natural modesty of his disposition was excessive, approaching even to timidity, he indulged in the most bold and sweeping generalisations, and he inspired all his scholars with a most implicit faith in his doctrines. Their admiration of his genius, and the feelings of gratitude and friendship which they all felt for him, were not undeserved; but the supreme authority usurped by him over the opinions of his contemporaries was eventually prejudicial to the progress of the science; so much so, as

* Cuvier, Éloge de Werner.

greatly to counterbalance the advantages which it derived from his exertions. If it be true that delivery be the first, second, and third requisite in a popular orator, it is no less certain, that to travel is of first, second, and third importance to those who desire to originate just and comprehensive views concerning the structure of our globe. Now Werner had not travelled to distant countries; he had merely explored a small portion of Germany, and conceived and persuaded others to believe that the whole surface of our planet, and all the mountain-chains in the world, were made after the model of his own province. It became a ruling object of ambition in the minds of his pupils to confirm the generalisations of their great master, and to discover in the most distant parts of the globe his 'universal formations,' which he supposed had been each in succession simultaneously precipitated over the whole earth from a common menstruum, or 'chaotic fluid.' It now appears that the Saxon professor had misinterpreted many of the most important appearances even in the immediate neighbourhood of Freyberg. Thus, for example, within a day's journey of his school, the porphyry, called by him primitive, has been found not only to send forth veins or dikes through strata of the coal formation, but to overlie them in mass. The granite of the Hartz mountains, on the other hand, which he supposed to be the nucleus of the chain, is now well known to traverse the other beds, as near Goslar; and still nearer Freyberg, in the Erzgebirge, the mica slate does not mantle round the granite as was supposed, but abuts abruptly against it. Fragments, also, of the greywacke slate, containing organic remains, were found entangled in the granite of the Hartz, by M. de Seckendorf.*

The principal merit of Werner's system of instruction consisted in steadily directing the attention of his scholars to the constant relations of superposition of certain mineral groups; but he had been anticipated, as has been shown in the last chapter, in the discovery of this general law, by

* I am indebted for this information partly to Messrs. Sedgwick and Murchison, who have investigated the country, and partly to Dr. Charles Hartmann, the translator of this work into German.

several geologists in Italy and elsewhere; and his leading divisions of the secondary strata were at the same time, and independently, made the basis of an arrangement of the British strata by our countryman, William Smith, to whose work I shall refer in the sequel.

Controversy between the Vulcanists and Neptunists.—In regard to basalt and other igneous rocks, Werner's theory was original, but it was also extremely erroneous. The basalts of Saxony and Hesse, to which his observations were chiefly confined, consisted of tabular masses capping the hills, and not connected with the levels of existing valleys, like many in Auvergne and the Vivarais. These basalts, and all other rocks of the same family in other countries, were, according to him, chemical precipitates from water. He denied that they were the products of submarine volcanos; and even taught that, in the primeval ages of the world, there were no volcanos. His theory was opposed, in a twofold sense, to the doctrine of the permanent agency of the same causes in nature; for not only did he introduce, without scruple, many imaginary causes supposed to have once effected great revolutions in the earth, and then to have become extinct, but new ones also were feigned to have come into play in modern times; and, above all, that most violent instrument of change, the agency of subterranean heat.

So early as 1768, before Werner had commenced his mineralogical studies, Raspe had truly characterised the basalts of Hesse as of igneous origin. Arduino, we have seen, had pointed out numerous varieties of trap-rock in the Vicentin as analogous to volcanic products, and as distinctly referable to ancient submarine eruptions. Desmarest, as before stated (p. 61), had, in company with Fortis, examined the Vicentin in 1766, and confirmed Arduino's views. In 1772, Banks, Solander, and Troil compared the columnar basalt of Hecla with that of the Hebrides. Collini, in 1774, recognised the true nature of the igneous rocks on the Rhine, between Andernach and Bonn. In 1775, Guettard visited the Vivarais, and established the relation of basaltic currents to lavas. Lastly, in 1779, Faujas published his

description of the volcanos of the Vivarais and Velay, and showed how the streams of basalt had poured out from craters which still remain in a perfect state.*

Desmarest.—When sound opinions had thus for twenty years prevailed in Europe concerning the true nature of the ancient trap-rocks, Werner by his simple dictum caused a retrograde movement, and not only overturned the true theory, but substituted for it one of the most unphilosophical that can well be imagined. The continual ascendency of his dogmas on this subject was the more astonishing, because a variety of new and striking facts were daily accumulated in favour of the correct opinions previously entertained. Desmarest, after a careful examination of Auvergne, pointed out, first, the most recent volcanos which had their craters still entire, and their streams of lava conforming to the level of the present river-courses. He then showed that there were others of an intermediate epoch, whose craters were nearly effaced, and whose lavas were less intimately connected with the present valleys; and, lastly, that there were volcanic rocks, still more ancient, without any discernible craters or scoriæ, and bearing the closest analogy to rocks in other parts of Europe, the igneous origin of which was denied by the school of Freyberg.†

Desmarest's map of Auvergne was a work of uncommon merit. He first made a trigonometrical survey of the district, and delineated its physical geography with minute accuracy and admirable graphic power. He contrived, at the same time, to express without the aid of colours, many geological details, including the different ages, and sometimes even the structure, of the volcanic rocks, and distinguishing them from the fresh-water and the granitic. They alone who have carefully studied Auvergne, and traced the different lava streams from their craters to their termination,—the various isolated basaltic cappings,—the relation of some lavas to the present valleys,—the absence of such relations in others,—can appreciate the extraordinary fidelity of this elaborate work. No other district of equal dimensions in Europe exhibits, perhaps,

* Cuvier, Éloge de Desmarest.

† Journ. de Phys. vol. xiii. p. 115; and Mém. de l'Inst., Sciences mathémat. et phys. vol. vi. p. 219.

so beautiful and varied a series of phenomena; and, fortunately, Desmarest possessed at once the mathematical knowledge required for the construction of a map, skill in mineralogy, and a power of original generalisation.

Dolomieu—Montlosier, 1784–1788.—Dolomieu, another of Werner's contemporaries, had found prismatic basalt among the ancient lavas of Etna; and, in 1784, had observed the alternations of submarine lavas and calcareous strata in the Val di Noto, in Sicily.* In 1790, also, he described similar phenomena in the Vicentin and in the Tyrol.† Montlosier published, in 1788, an essay on the theory of the volcanos of Auvergne, combining accurate local observations with comprehensive views. Notwithstanding this mass of evidence, the scholars of Werner were prepared to support his opinions to their utmost extent; maintaining, in the fulness of their faith, that even obsidian was an aqueous precipitate. As they were blinded by their veneration for the great teacher, they were impatient of opposition, and soon imbibed the spirit of a faction; and their opponents, the Vulcanists, were not long in becoming contaminated with the same intemperate zeal. Ridicule and irony were weapons more frequently employed than arguments by the rival sects, till at last the controversy was carried on with a degree of bitterness almost unprecedented in questions of physical science. Desmarest alone, who had long before provided ample materials for refuting such a theory, kept aloof from the strife; and whenever a zealous Neptunist wished to draw the old man into an argument, he was satisfied with replying, 'Go and see.'‡

Hutton, 1788.—It would be contrary to all analogy, in matters of graver import, that a war should rage with such fury on the Continent, and that the inhabitants of our island should not mingle in the affray. Although in England the personal influence of Werner was wanting to stimulate men to the defence of the weaker side of the question, they contrived to find good reason for espousing the Wernerian errors with great enthusiasm. In order to explain the peculiar

* Journ. de Phys. xxv. p. 191.

† Ibid. tom. xxxvii. part ii. p. 200.

‡ Cuvier, Éloge de Desmarest.

motives which led many to enter, even with party feeling, into this contest, it will be necessary to present the reader with a sketch of the views unfolded by Hutton, a contemporary of the Saxon geologist. Hutton had been educated as a physician, but declining the practice of medicine, he resolved, when young, to remain content with the small independence inherited from his father, and thenceforth to give his undivided attention to scientific pursuits. He resided at Edinburgh, where he enjoyed the society of many men of high attainments, who loved him for the simplicity of his manners and the sincerity of his character. His application was unwearied; and he made frequent tours through different parts of England and Scotland, acquiring considerable skill as a mineralogist, and constantly arriving at grand and comprehensive views in geology. He communicated the results of his observations unreservedly and with the fearless spirit of one who was conscious that love of truth was the sole stimulus of his exertions. When at length he had matured his views, he published, in 1788, his 'Theory of the Earth,'* and the same, afterwards more fully developed in a separate work, in 1795. This treatise was the first in which geology was declared to be in no way concerned about 'questions as to the origin of things;' the first in which an attempt was made to dispense entirely with all hypothetical causes, and to explain the former changes of the earth's crust by reference exclusively to natural agents. Hutton laboured to give fixed principles to geology, as Newton had succeeded in doing to astronomy; but, in the former science, too little progress had been made towards furnishing the necessary data, to enable any philosopher, however great his genius, to realise so noble a project.

Huttonian theory.—'The ruins of an older world,' said Hutton, 'are visible in the present structure of our planet; and the strata which now compose our continents have been once beneath the sea, and were formed out of the waste of pre-existing continents. The same forces are still destroying, by chemical decomposition or mechanical violence, even the hardest rocks, and transporting the materials to the sea,

* Ed. Phil. Trans. 1788.

where they are spread out, and form strata analogous to those of more ancient date. Although loosely deposited along the bottom of the ocean, they become afterwards altered and consolidated by volcanic heat, and then heaved up, fractured, and contorted.'

Although Hutton had never explored any region of active volcanos, he had convinced himself that basalt and many other trap-rocks were of igneous origin, and that some of them had been injected in a melted state through fissures in the older strata. The compactness of these rocks, and their different aspect from that of ordinary lava, he attributed to their having cooled down under the pressure of the sea; and in order to remove the objections started against this theory, his friend, Sir James Hall, instituted a most curious and instructive series of chemical experiments, illustrating the crystalline arrangement and texture assumed by melted matter cooled under high pressure.

The absence of stratification in granite, and its analogy, in mineral character, to rocks which he deemed of igneous origin, led Hutton to conclude that granite also must have been formed from matter in fusion; and this inference he felt could not be fully confirmed, unless he discovered at the contact of granite and other strata a repetition of the phenomena exhibited so constantly by the trap-rocks. Resolved to try his theory by this test, he went to the Grampians, and surveyed the line of junction of the granite and superincumbent stratified masses, until he found in Glen Tilt, in 1785, the most clear and unequivocal proofs in support of his views. Veins of red granite are there seen branching out from the principal mass, and traversing the black micaceous schist and primary limestone. The intersected stratified rocks are so distinct in colour and appearance as to render the example in that locality most striking, and the alteration of the limestone in contact was very analogous to that produced by trap veins on calcareous strata. This verification of his system filled him with delight, and called forth such marks of joy and exultation, that the guides who accompanied him, says his biographer, were convinced that he must have discovered a vein of

silver or gold.* He was aware that the same theory would not explain the origin of the primary schists, but these he called primary, rejecting the term primitive, and was disposed to consider them as sedimentary rocks altered by heat, and that they originated in some other form from the waste of previously existing rocks.

By this important discovery of granite veins, to which he had been led by fair induction from an independent class of facts, Hutton prepared the way for the greatest innovation on the systems of his predecessors. Vallisneri had pointed out the general fact that there were certain fundamental rocks which contained no organic remains, and which he supposed to have been formed before the creation of living beings. Moro, Generelli, and other Italian writers, embraced the same doctrine; and Lehman regarded the mountains called by him primitive, as parts of the original nucleus of the globe. The same tenet was an article of faith in the school of Freyberg: and if anyone ventured to doubt the possibility of our being enabled to carry back our researches to the creation of the present order of things, the granitic rocks were triumphantly appealed to. On them seemed written, in legible characters, the memorable inscription—

> Dinanzi a me non fur cose create
> Se non eterne; †

and no small sensation was excited when Hutton seemed, with unhallowed hand, desirous to erase characters already regarded by many as sacred. 'In the economy of the world,' said the Scotch geologist, 'I can find no traces of a beginning, no prospect of an end;' a declaration the more startling when coupled with the doctrine, that all past changes on the globe had been brought about by the slow agency of existing causes. The imagination was first fatigued and overpowered by endeavouring to conceive the immensity of time required for the annihilation of whole

* Playfair's Works, vol. iv. p. 75.

† 'Before me things create were none, save things
Eternal.'
Dante's *Inferno*, canto iii., Cary's Translation.

continents by so insensible a process; and when the thoughts had wandered through these interminable periods, no resting-place was assigned in the remotest distance. The oldest rocks were represented to be of a derivative nature, the last of an antecedent series, and that, perhaps, one of many pre-existing worlds. Such views of the immensity of past time, like those unfolded by the Newtonian philosophy in regard to space, were too vast to awaken ideas of sublimity unmixed with a painful sense of our incapacity to conceive a plan of such infinite extent. Worlds are seen beyond worlds immeasurably distant from each other, and, beyond them all, innumerable other systems are faintly traced on the confines of the visible universe.

The characteristic feature of the Huttonian theory was, as before hinted, the exclusion of all causes not supposed to belong to the present order of nature. But Hutton had made no step beyond Hooke, Moro, and Raspe, in pointing out in what manner the laws now governing subterranean movements might bring about geological changes, if sufficient time be allowed. On the contrary, he seems to have fallen far short of some of their views, especially when he refused to attribute any part of the external configuration of the earth's crust to subsidence. He imagined that the continents were first gradually destroyed by aqueous degradation; and when their ruins had furnished materials for new continents, they were upheaved by violent convulsions. He therefore required alternate periods of general disturbance and repose: and such he believed had been, and would for ever be, the course of nature.

Generelli, in his exposition of Moro's system, had made a far nearer approximation towards reconciling geological appearances with the state of nature as known to us; for while he agreed with Hutton, that the decay and reproduction of rocks were always in progress, proceeding with the utmost uniformity, the learned Carmelite represented the repairs of mountains by elevation from below to be effected by an equally constant and synchronous operation. Neither of these theories, considered singly, satisfies all the conditions of the great problem, which a geologist, who rejects cosmo-

logical causes, is called upon to solve; but they probably contain together the germs of a perfect system. There can be no doubt, that periods of disturbance and repose have followed each other in succession in every region of the globe; but it may be equally true, that the energy of the subterranean movements has been always uniform as regards the *whole earth.* The force of earthquakes may for a cycle of years have been invariably confined, as it is now, to large but determinate spaces, and may then have gradually shifted its position, so that another region, which had for ages been at rest, became in its turn the grand theatre of action.

Playfair's illustrations of Hutton, 1797.—In the explanation proposed by Hutton, and by Playfair, the illustrator of his theory, respecting the origin of valleys, great stress was laid on the action of the rivers now flowing in them. They perhaps ascribed valleys in general too exclusively to this one cause. Yet Playfair, in speaking of the upper valley of the Rhone (see chap. xviii.), has shown that he did not wholly disregard the influence of subterranean movements, and of the waves of the sea, during the original emergence of the land.

Although Hutton's knowledge of mineralogy and chemistry was considerable, he possessed but little information concerning organic remains; they merely served him, as they did Werner, to characterise certain strata, and to prove their marine origin. The theory of former revolutions in organic life was not yet fully recognised; and without this class of proofs in support of the antiquity of the globe, the indefinite periods demanded by the Huttonian hypothesis appeared visionary to many; and some, who deemed the doctrine inconsistent with revealed truths, indulged very uncharitable suspicions of the motives of its author. They accused him of a deliberate design of reviving the heathen dogma of an 'eternal succession,' and of denying that this world ever had a beginning. Playfair, in the biography of his friend, has the following comment on this part of their theory: 'In the planetary motions, where geometry has carried the eye so far, both into the future and the past, we discover no mark either of the commencement or

termination of the present order. It is unreasonable, indeed, to suppose that such marks should anywhere exist. The Author of Nature has not given laws to the universe, which, like the institutions of men, carry in themselves the elements of their own destruction. He has not permitted in His works any symptom of infancy or of old age, or any sign by which we may estimate either their future or their past duration. *He may put an end, as He no doubt gave a beginning,* to the present system, at some determinate period of time; but we may rest assured that this great catastrophe will not be brought about by the laws now existing, and that it is not indicated by anything which we perceive.'*

The party feeling excited against the Huttonian doctrines, and the open disregard of candour and temper in the controversy, will hardly be credited by the reader, unless he recalls to his recollection that the mind of the English public was at that time in a state of feverish excitement. A class of writers in France had been labouring industriously for many years to diminish the influence of the clergy, by sapping the foundations of the Christian faith; and their success, and the consequences of the Revolution, had alarmed the most resolute minds, while the imagination of the more timid was continually haunted by dread of innovation, as by the phantom of some fearful dream.

Voltaire, 1730-1760.—Although Voltaire was actively engaged throughout the greater part of his literary career in a successful war against religious intolerance, and in defence of those who were persecuted for opinions to which they had been led by freedom of enquiry, yet he contemplated with no friendly feelings the cultivators of geology in general. He found that the most popular systems of geology had been accommodated with much ingenuity to the account given in Genesis of the creation and deluge, and he regarded the science as one which had been successfully enlisted by the theologians as an ally in their cause.

When ridiculing the theories of Burnet, Woodward, and other physico-theological writers, he declared that they were

* Playfair's Works, vol. iv. p. 55.

as fond of changes of scene on the face of the globe as were the populace at a play. 'Every one of them destroys and renovates the earth after his own fashion, as Descartes framed it: for philosophers put themselves without ceremony in the place of God, and think to create a universe with a word.'* In his anxiety to shake the popular belief in the universal deluge, he endeavoured to inculcate scepticism as to the real nature of fossil shells, and to recall from contempt the exploded dogma of the sixteenth century that they were sports of nature. Yet in his later writings, speaking of the fossil shells of Touraine, he admits their organic origin, and in another of his works we find him implying the true nature of the shells collected in the Alps and other places, by ascribing them to Eastern species which had fallen from the hats of pilgrims coming from Syria.

Cowper—Williams, 1785-1789.—Some faint idea may be formed of the obloquy to which geologists exposed themselves by announcing the most obvious results of their investigations, if we observe the manner in which they were mentioned even by the amiable poet Cowper. In his poem of 'The Task' he says:

> Some drill and bore
> The solid earth, and from the strata there
> Extract a register, by which we learn
> That He who made it, and revealed its date
> To Moses, was mistaken in its age.†

The date here alluded to for the creation of this planet, or rather of the universe, was 4004 years before the birth of Christ; a date which for more than eighty years before Cowper published 'The Task' had been printed in the authorised versions of the Bible in the margin of the first chapter of Genesis, and was regarded by millions with the same reverence as the text of the Bible itself. Cowper was probably as little aware as are the majority of the present readers of this version that this chronology was derived from the speculations of Usher, Archbishop of Armagh, and is

* Dissertation envoyée à l'Académie de Boulogne, sur les Changemens arrivés dans notre Globe.

† The Task, book iii., 'The Garden.

nowhere to be found in the narrative of the unknown author or authors of the Hebrew cosmogony.*

To pass over the works of many divines, it may be mentioned that among the foremost ranks of the intolerant at this period are found several laymen who had considerable claims to scientific reputation. Among these appears Williams, a mineral surveyor of Edinburgh, who published a 'Natural History of the Mineral Kingdom,' in 1789; a work of great merit for that day, and of practical utility, as containing the best account of the coal strata. In his preface he charges Hutton with 'warping everything to support the eternity of the world.'† He descants on the pernicious influence of such sceptical notions, as leading to downright infidelity and atheism, 'and as being nothing less than to depose the Almighty Creator of the universe from His office.'‡

De Luc—Kirwan, 1798.—De Luc, in the preliminary discourse to his Treatise on Geology§ says, 'the weapons have been changed by which revealed religion is attacked; it is now assailed by geology, and the knowledge of this science has become essential to theologians.' He imputes the failure of former geological systems to their having been anti-Mosaical. It might be supposed from these and other similar charges that the geologists of that age were animated by a polemical and aggressive spirit; but, on the contrary, those writers who were fortunate enough 'to discover the true causes of things,' rarely deserved another part of the poet's panegyric, '*Atque metus omnes subjecit pedibus.*' The caution, and even timid reserve, of many eminent authors in Italy and elsewhere from the early period to that at which we have now arrived is very apparent; and there can hardly be a doubt, that they subscribed to certain dogmas, and particularly to the first diluvian theory, out of deference to

* The date of 4004 years B.C. for the creation was published (see Horner, Presidential Address, Quart. Geo. Journ. 1861, p. lxix.) in 1701 in an edition of the Bible now to be seen in the British Museum, and is continued up to the present time (1871) in the large annual reprints given out from the Clarendon Press at Oxford.

† P. 557.

‡ P. 59.

§ London, 1809.

popular prejudices, rather than from conviction. If they were guilty of dissimulation, we may feel regret, but must not blame their want of moral courage, reserving rather our condemnation for the persecuting spirit of the times, which forced Galileo to abjure, and the two Jesuits to disclaim the theory of Newton.

According to De Luc, the first essential distinction to be made between the various phenomena exhibited on the surface of the earth was, to determine which were the results of causes still in action, and which had been produced by causes that had ceased to act. The form and composition of the mass of our continents, he said, and their existence above the level of the sea, must be ascribed to causes no longer in action. These continents emerged, at no very remote period, on the sudden retreat of the ocean, the waters of which made their way into subterranean caverns. The formation of the rocks which enter into the crust of the earth began with the precipitation of granite from a primordial liquid, after which other strata containing the remains of organised bodies were deposited, till at last the present sea remained as the residuum of the primordial liquid, and no longer continued to produce mineral strata.*

Kirwan, president of the Royal Academy of Dublin, a chemist and mineralogist of some merit, but who possessed much greater authority in the scientific world than he was entitled by his talents to enjoy, said, in the introduction to his 'Geological Essays, 1799,' 'that *sound* geology *graduated* into religion, and was required to dispel certain systems of atheism or infidelity, of which they had had recent experience.'† He was an uncompromising defender of the aqueous theory of all rocks, and was scarcely surpassed by Burnet and Whiston in his desire to adduce the Mosaic writings in confirmation of his opinions.

Hutton answered Kirwan's attacks with great warmth, and with the indignation justly excited by unmerited reproach. 'He had always displayed,' says Playfair, 'the utmost disposition to admire the beneficent design manifested in the

* Elementary Treatise on Geology. London, 1809. Translated by De la Fite.

† Introd. p. 2.

structure of the world; and he contemplated with delight those parts of his theory which made the greatest additions to our knowledge of final causes.' We may say with equal truth, that in no scientific works in our language can more eloquent passages be found, concerning the fitness, harmony, and grandeur of all parts of the creation, than in those of Playfair. They are evidently the unaffected expressions of a mind which contemplated the study of nature, as best calculated to elevate our conceptions of the attributes of the First Cause. At any other time the force and elegance of Playfair's style must have insured popularity to the Huttonian doctrines; but by a singular coincidence, Neptunianism and orthodoxy were now associated in the same creed; and the tide of prejudice ran so strong, that the majority were carried far away into the chaotic fluid, and other cosmological inventions of Werner. These fictions the Saxon professor had borrowed with little modification, and without any improvement, from his predecessors. They had not the smallest foundation either in Scripture or in common sense, and were probably approved of by many as being so ideal and unsubstantial, that they could never come into violent collision with any preconceived opinions.

William Smith, 1790.—While the tenets of the rival schools of Freyberg and Edinburgh were warmly espoused by devoted partisans, the labours of an individual, unassisted by the advantages of wealth or station in society, were almost unheeded. Mr. William Smith, an English surveyor, published his 'Tabular View of the British Strata' in 1790, wherein he proposed a classification of the secondary formations in the West of England. Although he had not communicated with Werner, it appeared by this work that he had arrived at the same views respecting the laws of superposition of stratified rocks; that he was aware that the order of succession of different groups was never inverted; and that they might be identified at very distant points by their peculiar organised fossils.

From the time of the appearance of the 'Tabular View,' the author laboured to construct a geological map of the whole of England; and with the greatest disinterestedness of mind,

communicated the results of his investigations to all who desired information, giving such publicity to his original views, as to enable his contemporaries almost to compete with him in the race. The execution of his map was completed in 1815, and remains a lasting monument of original talent and extraordinary perseverance; for he had explored the whole country on foot without the guidance of previous observers, or the aid of fellow-labourers, and had succeeded in throwing into natural divisions the whole complicated series of British rocks. D'Aubuisson, a distinguished pupil of Werner, paid a just tribute of praise to this remarkable performance, observing, that 'what many celebrated mineralogists had only accomplished for a small part of Germany in the course of half a century, had been effected by a single individual for the whole of England.'*

Werner invented a new language to express his divisions of rocks, and some of his technical terms, such as greywacke, gneiss, and others, passed current in every country in Europe. Smith adopted for the most part English provincial terms, often of barbarous sound, such as gault, cornbrash, clunch clay; and affixed them to subdivisions of the British series. Many of these still retain their place in our scientific classifications and attest his priority of arrangement.

MODERN PROGRESS OF GEOLOGY.

The contention of the rival factions of the Vulcanists and Neptunists had been carried to such a height, that these names had become terms of reproach; and the two parties had been less occupied in searching for truth, than for such arguments as might strengthen their own cause or serve to annoy their antagonists. A new school at last arose, which professed the strictest neutrality, and the utmost indifference to the systems of Werner and Hutton, and which resolved diligently to devote its labours to observation. The reaction, provoked by the intemperance of the conflicting parties, now produced a tendency to extreme caution. Speculative views were discountenanced, and, through fear of exposing

* See Dr. Fitton's Memoir, before cited, p 60.

themselves to the suspicion of a bias towards the dogmas of a party, some geologists became anxious to entertain no opinion whatever on the causes of phenomena, and were inclined to scepticism even where the conclusions deducible from observed facts scarcely admitted of reasonable doubt.

Geological Society of London, 1807.—But although the reluctance to theorise was carried somewhat to excess, no measure could be more salutary at such a moment than a suspension of all attempts to form what were termed 'theories of the earth.' A great body of new data was required; and the Geological Society of London, founded in 1807, conduced greatly to the attainment of this desirable end. To multiply and record observations, and patiently to await the result at some future period, was the object proposed by them; and it was their favourite maxim that the time was not yet come for a general system of geology, but that all must be content for many years to be exclusively engaged in furnishing materials for future generalisations. By acting up to these principles with consistency, they in a few years disarmed all prejudice, and rescued the science from the imputation of being a dangerous, or at best but a visionary pursuit.

A distinguished modern writer has with truth remarked, that the advancement of three of the main divisions of geological enquiry has, since the middle of the eighteenth century, been promoted successively by three different nations of Europe—the Germans, the English, and the French.* We have seen that the systematic study of what may be called mineralogical geology had its origin and chief point of activity in Germany, where Werner first described with precision the mineral characters of rocks. The classification of the secondary formations, each marked by their peculiar fossils, belongs, in a great measure, to England, where the labours before alluded to of Smith, and those of the most active members of the Geological Society of London, were steadily directed to these objects. The foundation of the third branch, that relating to the tertiary formations, was

* Whewell, British Critic, No. xvii. p. 187. 1831.

laid in France by the splendid work of Cuvier and Brongniart, published in 1808, 'On the Mineral Geography and Organic Remains of the Neighbourhood of Paris.'

We may still trace, in the language of the science and our present methods of arrangement, the various countries where the growth of these several departments of geology was at different times promoted. Many names of simple minerals and rocks remain to this day German; while the European divisions of the secondary strata are in great part English, and are, indeed, often founded too exclusively on English types. Lastly, the subdivisions first established in the Paris basin have served as normal groups to which other tertiary deposits throughout Europe have been compared, even in cases where this standard was wholly inapplicable.

No period could have been more fortunate for the discovery, in the immediate neighbourhood of Paris, of a rich store of well-preserved fossils, than the commencement of the present century; for at no former era had Natural History been cultivated with such enthusiasm in the French metropolis. The labours of Cuvier in comparative osteology, and of Lamarck in recent and fossil shells, had raised these departments of study to a rank of which they had never previously been deemed susceptible. Their investigations had eventually a powerful effect in dispelling the illusion which had long prevailed concerning the absence of analogy between the ancient and modern state of our planet. A close comparison of the recent and fossil species, and the inferences drawn in regard to their habits, accustomed the geologist to contemplate the earth as having been at successive periods the dwelling-place of animals and plants of different races, some terrestrial, and others aquatic—some fitted to live in seas, others in the waters of lakes and rivers. By the consideration of these topics, the mind was slowly and insensibly withdrawn from imaginary pictures of catastrophes and chaotic confusion, such as haunted the imagination of the early cosmogonists. Numerous proofs were discovered of the tranquil deposition of sedimentary matter, and the slow development of organic life. If many writers, and Cuvier himself in the number, still continued to maintain that 'the thread of

induction was broken,'* yet, in reasoning by the strict rules of induction from recent to fossil species, they in a great measure disclaimed the dogma which in theory they professed. The adoption of the same generic, and, in some cases, even of the same specific, names for the exuviæ of fossil animals and their living analogues, was an important step towards familiarising the mind with the idea of the identity and unity of the system in distant eras. It was an acknowledgment, as it were, that part at least of the ancient memorials of nature were written in a living language. The growing importance, then, of the natural history of organic remains may be pointed out as the characteristic feature of the progress of the science during the present century. This branch of knowledge has already become an instrument of great utility in geological classification, and is continuing daily to unfold new data for grand and enlarged views respecting the former changes of the earth.

When we compare the results of observations in this century with those of the three preceding centuries, we cannot but look forward with the most sanguine expectations to the degree of excellence to which geology may be carried, even by the labours of the present generation. Never, perhaps, did any science, with the exception of astronomy, unfold, in an equally brief period, so many novel and unexpected truths, and overturn so many preconceived opinions. The senses had for ages declared the earth to be at rest, until the astronomer taught that it was carried through space with inconceivable rapidity. In like manner was the surface of this planet regarded as having remained unaltered since its creation, until the geologist proved that it had been the theatre of reiterated change, and was still the subject of slow but never-ending fluctuations. The discovery of other systems in the boundless regions of space was the triumph of astronomy; to trace the same system through various transformations—to behold it at successive eras adorned with different hills and valleys, lakes and seas, and peopled with new inhabitants, was the delightful meed of geological research. By the geometer

* Discours sur les Révolutions de la Terre.

were measured the regions of space, and the relative distances of the heavenly bodies;—by the geologist myriads of ages were reckoned, not by arithmetical computation, but by a train of physical events—a succession of phenomena in the animate and inanimate worlds—signs which convey to our minds more definite ideas than figures can do of the immensity of time.

Whether our investigation of the earth's history and structure will eventually be productive of as great practical benefits to mankind as a knowledge of the distant heavens, must remain for the decision of posterity. It was not till astronomy had been enriched by the observations of many centuries, and had made its way against popular prejudices to the establishment of a sound theory, that its application to the useful arts was most conspicuous. The cultivation of geology began at a later period; and in every step which it has hitherto made towards sound theoretical principles, it has had to contend against more violent prepossessions. The practical advantages already derived from it have not been inconsiderable; but our generalisations are yet imperfect, and they who come after us may be expected to reap the most valuable fruits of our labour. Meanwhile the charm of first discovery is our own; and, as we explore this magnificent field of enquiry, the sentiment of a great historian of our times may continually be present to our minds, that 'he who calls what has vanished back again into being enjoys a bliss like that of creating.'*

* Niebuhr's Hist. of Rome, vol. i. p. 5. Hare and Thirlwall's translation.

CHAPTER V.

PREJUDICES WHICH HAVE RETARDED THE PROGRESS OF GEOLOGY.

PREPOSSESSIONS IN REGARD TO THE DURATION OF PAST TIME—PREJUDICES ARISING FROM OUR PECULIAR POSITION AS INHABITANTS OF THE LAND—OTHERS OCCASIONED BY OUR NOT SEEING SUBTERRANEAN CHANGES NOW IN PROGRESS—ALL THESE CAUSES COMBINE TO MAKE THE FORMER COURSE OF NATURE APPEAR DIFFERENT FROM THE PRESENT—OBJECTIONS TO THE DOCTRINE THAT CAUSES SIMILAR IN KIND AND ÉNERGY TO THOSE NOW ACTING, HAVE PRODUCED THE FORMER CHANGES OF THE EARTH'S SURFACE, CONSIDERED.

If we reflect on the history of the progress of geology, as explained in the preceding chapters, we perceive that there have been great fluctuations of opinion respecting the nature of the causes to which all former changes of the earth's surface are referable. The first observers conceived the monuments which the geologist endeavours to decipher to relate to an original state of the earth, or to a period when there were causes in activity, distinct, in kind and degree, from those now constituting the economy of nature. These views were gradually modified, and some of them entirely abandoned, in proportion as observations were multiplied, and the signs of former mutations were skilfully interpreted. Many appearances, which had for a long time been regarded as indicating mysterious and extraordinary agency, were finally recognised as the necessary result of the laws now governing the material world; and the discovery of this unlooked-for conformity has at length induced some philosophers to infer, that, during the ages contemplated in geology, there has never been any interruption to the agency of the same uniform laws of change. The same assemblage of general causes, they conceive, may have been sufficient to produce, by their various combinations, the

endless diversity of effects, of which the shell of the earth has preserved the memorials; and, consistently with these principles, the recurrence of analogous changes is expected by them in time to come.

Whether we coincide or not in this doctrine, we must admit that the gradual progress of opinion concerning the succession of phenomena in very remote eras, resembles, in a singular manner, that which has accompanied the growing intelligence of every people, in regard to the economy of nature in their own times. In an early state of advancement, when a greater number of natural appearances are unintelligible, an eclipse, an earthquake, a flood, or the approach of a comet, with many other occurrences afterwards found to belong to the regular course of events, are regarded as prodigies. The same delusion prevails as to moral phenomena, and many of these are ascribed to the intervention of demons, ghosts, witches, and other immaterial and supernatural agents. By degrees, many of the enigmas of the moral and physical world are explained, and, instead of being due to extrinsic and irregular causes, they are found to depend on fixed and invariable laws. The philospher at last becomes convinced of the undeviating uniformity of secondary causes; and, guided by his faith in this principle, he determines the probability of accounts transmitted to him of former occurrences, and often rejects the fabulous tales of former times, on the ground of their being irreconcilable with the experience of more enlightened ages.

Prepossessions in regard to the duration of past time.—As a belief in the want of conformity in the causes by which the earth's crust has been modified in ancient and modern periods was, for a long time, universally prevalent, and that, too, amongst men who were convinced that the order of nature had been uniform for the last several thousand years, every circumstance which could have influenced their minds and given an undue bias to their opinions deserves particular attention. Now the reader may easily satisfy himself, that, however undeviating the course of nature may have been from the earliest epochs, it was impossible for the first cultivators of geology to come to such a conclusion, so long

as they were under a delusion as to the age of the world, and the date of the first creation of animate beings. However fantastical some theories of the sixteenth century may now appear to us,—however unworthy of men of great talent and sound judgment,—we may rest assured that, if the same misconception now prevailed in regard to the memorials of human transactions, it would give rise to a similar train of absurdities. Let us imagine, for example, that Champollion, and the French and Tuscan literati when engaged in exploring the antiquities of Egypt, had visited that country with a firm belief that the banks of the Nile were never peopled by the human race before the beginning of the nineteenth century, and that their faith in this dogma was as difficult to shake as the opinion of our ancestors, that the earth was never the abode of living beings until the creation of the present continents, and of the species now existing,—it is easy to perceive what extravagant systems they would frame, while under the influence of this delusion, to account for the monuments discovered in Egypt. The sight of the pyramids, obelisks, colossal statues, and ruined temples, would fill them with such astonishment, that for a time they would be as men spell-bound—wholly incapable of reasoning with sobriety. They might incline at first to refer the construction of such stupendous works to some superhuman powers of a primeval world. A system might be invented resembling that so gravely advanced by Manetho, who relates that a dynasty of gods originally ruled in Egypt, of whom Vulcan, the first monarch, reigned nine thousand years; after whom came Hercules and other demigods, who were at last succeeded by human kings.

When some fanciful speculations of this kind had amused their imaginations for a time, some vast repository of mummies would be discovered, and would immediately undeceive those antiquaries who enjoyed an opportunity of personally examining them; but the prejudices of others at a distance, who were not eye-witnesses of the whole phenomena, would not be so easily overcome. The concurrent report of many travellers would, indeed, render it necessary for them to accommodate ancient theories to some of the new facts, and

much wit and ingenuity would be required to modify and defend their old positions. Each new invention would violate a greater number of known analogies; for if a theory be required to embrace some false principle, it becomes more visionary in proportion as facts are multiplied, as would be the case if geometers were now required to form an astronomical system on the assumption of the immobility of the earth.

Amongst other fanciful conjectures concerning the history of Egypt, we may suppose some of the following to be started. 'As the banks of the Nile have been so recently colonised for the first time, the curious substances called mummies could never in reality have belonged to men. They may have been generated by some *plastic virtue* residing in the interior of the earth, or they may be abortions of Nature produced by her incipient efforts in the work of creation. For if deformed beings are sometimes born even now, when the scheme of the universe is fully developed, many more may have been "sent before their time, scarce half made up," when the planet itself was in the embryo state. But if these notions appear to derogate from the perfection of the Divine attributes, and if these mummies be in all their parts true representations of the human form, may we not refer them to the future rather than the past? May we not be looking into the womb of Nature, and not her grave? May not these images be like the shades of the unborn in Virgil's Elysium—the archetypes of men not yet called into existence?'

These speculations, if advocated by eloquent writers, would not fail to attract many zealous votaries, for they would relieve men from the painful necessity of renouncing preconceived opinions. Incredible as such scepticism may appear, it has been rivalled by many systems of the sixteenth and seventeenth centuries, and among others by that of the learned Falloppio, who, as we have seen (p. 33), regarded the tusks of fossil elephants as earthy concretions, and the pottery or fragments of vases in the Monte Testaceo, near Rome, as works of nature, and not of art. But when one generation had passed away, and another, not compromised to the

support of antiquated dogmas, had succeeded, they would review the evidence afforded by mummies more impartially, and would no longer controvert the preliminary question, that human beings had lived in Egypt before the nineteenth century: so that when a hundred years perhaps had been lost, the industry and talents of the philosopher would be at last directed to the elucidation of points of real historical importance.

But the above arguments are aimed against one only of many prejudices with which the early geologists had to contend. Even when they conceded that the earth had been peopled with inanimate beings at an earlier period than was at first supposed, they had no conception that the quantity of time bore so great a proportion to the historical era as is now generally conceded. How fatal every error as to the quantity of time must prove to the introduction of rational views concerning the state of things in former ages, may be conceived by supposing the annals of the civil and military transactions of a great nation to be perused under the impression that they occurred in a period of one hundred instead of two thousand years. Such a portion of history would immediately assume the air of a romance; the events would seem devoid of credibility, and inconsistent with the present course of human affairs. A crowd of incidents would follow each other in thick succession. Armies and fleets would appear to be assembled only to be destroyed, and cities built merely to fall in ruins. There would be the most violent transitions from foreign or intestine war to periods of profound peace, and the works effected during the years of disorder or tranquillity would appear alike superhuman in magnitude.

He who should study the monuments of the natural world under the influence of a similar infatuation, must draw a no less exaggerated picture of the energy and violence of causes, and must experience the same insurmountable difficulty in reconciling the former and present state of nature. If we could behold in one view all the volcanic cones thrown up in Iceland, Italy, Sicily, and other parts of Europe, during the last five thousand years, and could see the lavas

which have flowed during the same period; the dislocations, subsidences, and elevations caused during earthquakes; the lands added to various deltas, or devoured by the sea, together with the effects of devastation by floods, and imagine that all these events had happened in one year, we must form most exalted ideas of the activity of the agents, and the suddenness of the revolutions. If geologists, therefore, have misinterpreted the signs of a succession of events, so as to conclude that centuries were implied where the characters indicated thousands of years, and thousands of years where the language of Nature signified millions, they could not, if they reasoned logically from such false premises, come to any other conclusion than that the system of the natural world had undergone a complete revolution.

We should be warranted in ascribing the erection of the great pyramid to superhuman power, if we were convinced that it was raised in one day; and if we imagine, in the same manner, a continent or mountain-chain to have been elevated during an equally small fraction of the time which was really occupied in upheaving it, we might then be justified in inferring, that the subterranean movements were once far more energetic than in our own times. We know that during one earthquake the coast of Chili may be raised for a hundred miles to the average height of about three feet. A repetition of two thousand shocks, of equal violence, might produce a mountain-chain one hundred miles long, and six thousand feet high. Now, should one or two only of these convulsions happen in a century, it would be consistent with the order of events experienced by the Chilians from the earliest times: but if the whole of them were to occur in the next hundred years, the entire district must be depopulated, scarcely any animals or plants could survive, and the surface would be one confused heap of ruin and desolation.

One consequence of undervaluing greatly the quantity of past time, is the apparent coincidence which it occasions of events necessarily disconnected, or which are so unusual, that it would be inconsistent with all calculation of chances to suppose them to happen at one and the same time. When the unlooked-for association of such rare phenomena is

witnessed in the present course of nature, it scarcely ever fails to excite a suspicion of the preternatural in those minds which are not firmly convinced of the uniform agency of secondary causes;—as if the death of some individual in whose fate they are interested happens to be accompanied by the appearance of a luminous meteor, or a comet, or the shock of an earthquake. It would be only necessary to multiply such coincidences indefinitely, and the mind of every philosopher would be disturbed. Now it would be difficult to exaggerate the number of physical events, many of them most rare and unconnected in their nature, which were imagined by the Woodwardian hypothesis to have happened in the course of a few months: and numerous other examples might be found of popular geological theories, which require us to imagine that a long succession of events happened in a brief and almost momentary period.

Another liability to error, very nearly allied to the former, arises from the frequent contact of geological monuments referring to very distant periods of time. We often behold, at one glance, the effects of causes which have acted at times incalculably remote, and yet there may be no striking circumstances to mark the occurrence of a great chasm in the chronological series of Nature's archives. In the vast interval of time which may really have elapsed between the results of operations thus compared, the physical condition of the earth may, by slow and insensible modifications, have become entirely altered; one or more races of organic beings may have passed away, and yet have left behind, in the particular region under contemplation, no trace of their existence.

To a mind unconscious of these intermediate events, the passage from one state of things to another must appear so violent, that the idea of revolutions in the system inevitably suggests itself. The imagination is as much perplexed by the deception, as it might be if two distant points in space were suddenly brought into immediate proximity. Let us suppose, for a moment, that a philosopher should lie down to sleep in some arctic wilderness, and then be transferred by a power, such as we read of in tales of enchantment, to a valley in a tropical country, where, on awaking, he might

find himself surrounded by birds of brilliant plumage, and all the luxuriance of animal and vegetable forms of which Nature is so prodigal in those regions. The most reasonable supposition, perhaps, which he could make, if by the necromancer's art he were placed in such a situation, would be, that he was dreaming; and if a geologist form theories under a similar delusion, we cannot expect him to preserve more consistency in his speculations than in the train of ideas in an ordinary dream.

It may afford, perhaps, a more lively illustration of the principle here insisted upon, if I recall to the reader's recollection the legend of the Seven Sleepers. The scene of that popular fable was placed in the two centuries which elapsed between the reign of the emperor Decius and the death of Theodosius the younger. In that interval of time (between the years 249 and 450 of our era) the union of the Roman empire had been dissolved, and some of its fairest provinces overrun by the barbarians of the north. The seat of government had passed from Rome to Constantinople, and the throne from a pagan persecutor to a succession of Christian and orthodox princes. The genius of the empire had been humbled in the dust, and the altars of Diana and Hercules were on the point of being transferred to Catholic saints and martyrs. The legend relates, 'that when Decius was still persecuting the Christians, seven noble youths of Ephesus concealed themselves in a spacious cavern in the side of an adjacent mountain, where they were doomed to perish by the tyrant, who gave orders that the entrance should be firmly secured with a pile of huge stones. They immediately fell into a deep slumber, which was miraculously prolonged, without injuring the powers of life, during a period of 187 years. At the end of that time the slaves of Adolius, to whom the inheritance of the mountain had descended, removed the stones to supply materials for some rustic edifice: the light of the sun darted into the cavern, and the seven sleepers were permitted to awake. After a slumber, as they thought, of a few hours, they were pressed by the calls of hunger, and resolved that Jamblichus, one of their number, should secretly return to the city to purchase bread

for the use of his companions. The youth could no longer recognise the once familiar aspect of his native country, and his surprise was increased by the appearance of a large cross triumphantly erected over the principal gate of Ephesus. His singular dress and obsolete language confounded the baker, to whom he offered an ancient medal of Decius as the current coin of the empire; and Jamblichus, on the suspicion of a secret treasure, was dragged before the judge. Their mutual enquiries produced the amazing discovery, that two centuries were almost elapsed since Jamblichus and his friends had escaped from the rage of a pagan tyrant.'

This legend was received as authentic throughout the Christian world before the end of the sixth century, and was afterwards introduced by Mahomet as a divine revelation into the Koran, and from hence was adopted and adorned by all the nations from Bengal to Africa who professed the Mahometan faith. Some vestiges even of a similar tradition have been discovered in Scandinavia. 'This easy and universal belief,' observes the philosophical historian of the Decline and Fall, 'so expressive of the sense of mankind, may be ascribed to the genuine merit of the fable itself. We imperceptibly advance from youth to age, without observing the gradual, but incessant, change of human affairs; and even in our larger experience of history, the imagination is accustomed, by a perpetual series of causes and effects, to unite the most distant revolutions. But if the interval between two memorable eras could be instantly annihilated; if it were possible, after a momentary slumber of two hundred years, to display the new world to the eyes of a spectator who still retained a lively and recent impression of the old, his surprise and his reflections would furnish the pleasing subject of a philosophical romance.'*

Prejudices arising from our peculiar position as inhabitants of the land.—The sources of prejudice hitherto considered may be deemed peculiar for the most part to the infancy of the science, but others are common to the first cultivators of

* Gibbon, Decline and Fall, chap. xxxiii.

geology and to ourselves, and are all singularly calculated to produce the same deception, and to strengthen our belief that the course of nature in the earlier ages differed widely from that now established. Although these circumstances cannot be fully explained without assuming some things as proved, which it has been my object elsewhere to demonstrate,* it may be well to allude to them briefly in this place.

The first and greatest difficulty, then, consists in an habitual unconsciousness that our position as observers is essentially unfavourable, when we endeavour to estimate the nature and magnitude of the changes now in progress. In consequence of our inattention to this subject, we are liable to serious mistakes in contrasting the present with former states of the globe. As dwellers on the land, we inhabit about a fourth part of the surface; and that portion is almost exclusively a theatre of decay, and not of reproduction. We know, indeed, that new deposits are annually formed in seas and lakes, and that every year some new igneous rocks are produced in the bowels of the earth, but we cannot watch the progress of their formation; and as they are only present to our minds by the aid of reflection, it requires an effort both of the reason and the imagination to appreciate duly their importance. It is, therefore, not surprising that we estimate very imperfectly the result of operations thus unseen by us; and that, when analogous results of former epochs are presented to our inspection, we cannot immediately recognise the analogy. He who has observed the quarrying of stone from a rock, and has seen it shipped for some distant port, and then endeavours to conceive what kind of edifice will be raised by the materials, is in the same predicament as a geologist, who, while he is confined to the land, sees the decomposition of rocks, and the transportation of matter by rivers to the sea, and then endeavours to picture to himself the new strata which Nature is building beneath the waters.

Prejudices arising from our not seeing subterranean changes.—Nor is his position less unfavourable when, beholding a volcanic eruption, he tries to conceive what changes the

* Elements of Geology, 6th edit., 1865; and Student's Elements, 2nd edit., 1874.

column of lava has produced, in its passage upwards, on the intersected strata; or what form the melted matter may assume at great depths on cooling; or what may be the extent of the subterranean rivers and reservoirs of liquid matter far beneath the surface. It should, therefore, be remembered, that the task imposed on those who study the earth's history requires no ordinary share of discretion; for we are precluded from collating the corresponding parts of the system of things as it exists now, and as it existed at former periods. If we were inhabitants of another element—if the great ocean were our domain, instead of the narrow limits of the land, our difficulties would be considerably lessened; while, on the other hand, there can be little doubt, although the reader may, perhaps, smile at the bare suggestion of such an idea, that an amphibious being, who should possess our faculties, would still more easily arrive at sound theoretical opinions in geology, since he might behold, on the one hand, the decomposition of rocks in the atmosphere, or the transportation of matter by running water; and, on the other, examine the deposition of sediment in the sea, and the imbedding of animal and vegetable remains in new strata. He might ascertain, by direct observation, the action of a mountain torrent, as well as of a marine current; might compare the products of volcanos poured out upon the land with those ejected beneath the waters; and might mark, on the one hand, the growth of the forest, and, on the other, that of the coral reef. Yet, even with these advantages, he would be liable to fall into the greatest errors, when endeavouring to reason on rocks of subterranean origin. He would seek in vain, within the sphere of his observation, for any direct analogy to the process of their formation, and would therefore be in danger of attributing them, wherever they are upraised to view, to some 'primeval state of nature.'

But if we may be allowed so far to indulge the imagination, as to suppose a being entirely confined to the nether world—some 'dusky melancholy sprite,' like Umbriel, who could 'flit on sooty pinions to the central earth,' but who was never permitted to 'sully the fair face of light,' and emerge into the regions of water and of air; and if this

being should busy himself in investigating the structure of the globe, he might frame theories the exact converse of those usually adopted by human philosophers. He might infer that the stratified rocks, containing shells and other organic remains, were the oldest of created things, belonging to some original and nascent state of the planet. 'Of these masses,' he might say, 'whether they consist of loose incoherent sand, soft clay, or solid stone, none have been formed in modern times. Every year some of them are broken and shattered by earthquakes, or melted by volcanic fire; and when they cool down slowly from a state of fusion, they assume a new and more crystalline form, no longer exhibiting that stratified disposition and those curious impressions and fantastic markings, by which they were previously characterised. This process cannot have been carried on for an indefinite time, for in that case all the stratified rocks would long ere this have been fused and crystallised. It is therefore probable that the whole planet once consisted of these mysterious and curiously bedded formations at a time when the volcanic fire had not yet been brought into activity. Since that period there seems to have been a gradual development of heat; and this augmentation we may expect to continue till the whole globe shall be in a state of fluidity, or shall consist, in those parts which are not melted, of volcanic and crystalline rocks.'

Such might be the system of the Gnome at the very time that the followers of Leibnitz, reasoning on what they saw on the outer surface, might be teaching the opposite doctrine of gradual refrigeration, and averring that the earth had begun its career as a fiery comet, and might be destined hereafter to become a frozen mass. The tenets of the schools of the nether and of the upper world would be directly opposed to each other, for both would partake of the prejudices inevitably resulting from the continual contemplation of one class of phenomena to the exclusion of another. Man observes the annual decomposition of crystalline and igneous rocks, and may sometimes see their conversion into stratified deposits; but he cannot witness the reconversion of the

sedimentary into the crystalline by subterranean heat. He is in the habit of regarding all the sedimentary rocks as more recent than the unstratified, for the same reason that we may suppose him to fall into the opposite error if he saw the origin of the igneous class only.

For more than two centuries the shelly strata of the Subapennine hills afforded matter of speculation to the early geologists of Italy, and few of them had any suspicion that similar deposits were then forming in the neighbouring sea. Some imagined that the strata, so rich in organic remains, instead of being due to secondary agents, had been so created in the beginning of things by the fiat of the Almighty. Others, as we have seen, ascribed the imbedded fossil bodies to some plastic power which resided in the earth in the early ages of the world. In what manner were these dogmas at length exploded? The fossil relics were carefully compared with their living analogues, and all doubts as to their organic origin were eventually dispelled. So, also, in regard to the nature of the containing beds of mud, sand, and limestone: those parts of the bottom of the sea were examined where shells are now becoming annually entombed in new deposits. Donati explored the bed of the Adriatic, and found the closest resemblance between the strata there forming, and those which constituted hills above a thousand feet high in various parts of the Italian peninsula. He ascertained by dredging that living testacea were there grouped together in precisely the same manner as were their fossil analogues in the inland strata; and while some of the recent shells of the Adriatic were becoming incrusted with calcareous rock, he observed that others had been newly buried in sand and clay, precisely as fossil shells occur in the Subapennine hills.

In like manner, the volcanic rocks of the Vicentin had been studied in the beginning of the last century; but no geologist suspected, before the time of Arduino, that these were composed of ancient submarine lavas. During many years of controversy, the popular opinion inclined to a belief that basalt and rocks of the same class had been precipitated from a chaotic fluid, or an ocean which rose at succes-

sive periods over the continents, charged with the component elements of the rocks in question. Few will now dispute that it would have been difficult to invent a theory more distant from the truth; yet we must cease to wonder that it gained so many proselytes, when we remember that its claims to probability arose partly from the very circumstance of its confirming the assumed want of analogy between geological causes and those now in action. By what train of investigations were geologists induced at length to reject these views, and to assent to the igneous origin of the trappean formations? By an examination of volcanos now active, and by comparing their structure and the composition of their lavas with the ancient trap rocks.

The establishment, from time to time, of numerous points of identification, drew at length from geologists a reluctant admission, that there was more correspondence between the condition of the globe at remote eras and now, and more uniformity in the laws which have regulated the changes of its surface, than they at first imagined. If, in this state of the science, they still despaired of reconciling every class of geological phenomena to the operations of ordinary causes, even by straining analogy to the utmost limits of credibility, we might have expected, at least, that the balance of probability would now have been presumed to incline towards the close analogy of the ancient and modern causes. But, after repeated experience of the failure of attempts to speculate on geological monuments, as belonging to a distinct order of things, new sects continued to persevere in the principles adopted by their predecessors. They still began, as each new problem presented itself, whether relating to the animate or inanimate world, to assume an original and dissimilar order of nature; and when at length they approximated, or entirely came round to an opposite opinion, it was always with the feeling, that they were conceding what they had been justified *à priori* in deeming improbable. In a word, the same men who, as natural philosophers, would have been most incredulous respecting any extraordinary deviations from the known course of nature, if reported to have happened *in their own time*, were equally disposed, as geologists,

to expect the proofs of such deviations at every period of the past.

I shall proceed in the following chapters to enumerate some of the principal difficulties still opposed to the theory of the uniform nature and energy of the causes which have worked successive changes in the crust of the earth, and in the condition of its living inhabitants. The discussion of so important a question on the present occasion may appear premature, but it is one which naturally arises out of a review of the former history of the science. It is, of course, impossible to enter into such speculative topics, without occasionally carrying the novice beyond his depth, and appealing to facts and conclusions with which he will be unacquainted, until he has studied some elementary work on geology, but it may be useful to excite his curiosity, and lead him to study such works by calling his attention at once to some of the principal points of controversy.*

* In the earlier editions of this work, a fourth book was added on Geology Proper, or Systematic Geology, containing an account of the former changes of the animate and inanimate creation, brought to light by an examination of the crust of the earth. This I afterwards (in 1838) expanded into a separate publication called the Elements or Manual of Geology, of which a sixth edition appeared, January 1865, and the greater part of which is embodied in the Student's Elements, a second edition of which was published in 1874.

CHAPTER VI.

SUPPOSED INTENSITY OF AQUEOUS FORCES AT REMOTE PERIODS.

INTENSITY OF AQUEOUS CAUSES—SLOW ACCUMULATION OF STRATA PROVED BY FOSSILS—RATE OF DENUDATION CAN ONLY KEEP PACE WITH DEPOSITION—ERRATICS, AND ACTION OF ICE—DELUGES, AND THE CAUSES TO WHICH THEY ARE REFERRED—SUPPOSED UNIVERSALITY OF ANCIENT DEPOSITS.

Intensity of aqueous causes.—The great problem alluded to at the close of the last chapter may thus be stated, whether the former changes of the earth made known to us by geology resemble in kind and degree those now in daily progress. This question may be contemplated from several points of view, and it embraces among other subjects the enquiry, whether there are any grounds for the belief entertained by many, that the intensity both of aqueous and of igneous forces, in remote ages, far exceeded that which we witness in our own times.

First, then, as to aqueous causes: it has been shown in our history of the science, that Woodward did not hesitate, in 1695, to teach that the entire mass of fossiliferous strata contained in the earth's crust had been deposited in a few months; and, consequently, as their mechanical and derivative origin was already admitted, the reduction of rocky masses into mud, sand, and pebbles, the transportation of the same to a distance, and their accumulation elsewhere in regular strata, were all assumed to have taken place with a rapidity unparalleled in modern times. This doctrine was modified by degrees, in proportion as different classes of organic remains, such as shells, corals, and fossil plants, had been studied with attention. Analogy led every naturalist to assume, that each full-grown individual of the animal or vegetable kingdom, had required a certain number of days,

months, or years for the attainment of maturity, and the perpetuation of its species by generation; and thus the first approach was made to the conception of a common standard of time, without which there are no means whatever of measuring the comparative rate at which any succession of events has taken place at two distinct periods. This standard consisted of the average duration of the lives of individuals of the same genera or families in the animal and vegetable kingdoms; and the multitude of fossils dispersed through successive strata implied the continuance of the same species for many generations. At length the idea that species themselves had had a limited duration, arose out of the observed fact that sets of strata of different ages contained fossils of distinct species. Finally, the opinion became general, that in the course of ages, one assemblage of animals and plants had disappeared after another again and again, and new tribes had started into life to replace them.

Denudation.—In addition to the proofs derived from organic remains, the forms of stratification led also, on a fuller investigation, to the belief that sedimentary rocks had been slowly deposited; but it was still supposed that *denudation*, or the power of running water, and the waves and currents of the ocean, to strip off superior strata, and lay bare the rocks below, had formerly operated with an energy wholly unequalled in our times. These opinions were both illogical and inconsistent, because deposition and denudation are processes inseparably connected, and what is true of the rate of one of them must be true of the rate of the other within very narrow limits, and the conveyance of solid matter to a particular region can only keep pace with its removal from another, so that the aggregate of sedimentary strata in the earth's crust can never exceed in volume the amount of solid matter which has been ground down and washed away by rivers, waves, and currents. How vast then must be the spaces which this abstraction of matter has left vacant! how far exceeding in dimensions all the valleys, however numerous, and the hollows, however vast, which we can prove to have been cleared out by aqueous erosion! The evidence of the work of denudation is defective, because it is the tendency of every destroying cause to obliterate, in great part, the

signs of its own agency. The amount of reproduction in the form of sedimentary strata will only afford a measure of the minimum of denudation which the earth's surface has undergone, because the same materials in a multitude of cases have been broken up again and again and re-stratified, so that the last alone of many forms through which they have passed is now presented to our view.

Erratics and ice-action.—Another phenomenon to which the advocates of the excessive power of running water in times past have appealed, is the enormous size of the blocks called *erratic*, which lie scattered over the northern parts of Europe and North America. Unquestionably a large proportion of these blocks have been transported far from their original position, for between them and the parent rocks we now find, not unfrequently, deep seas and valleys intervening, or hills more than a thousand feet high. To explain the present situation of such travelled fragments, a deluge of mud was imagined by some to have come from the north, bearing along with it sand, gravel, and stony fragments, some of them hundreds of tons in weight. This flood, in its transient passage over the continents, dispersed the boulders irregularly over hill, valley, and plain; or forced them along over a surface of hard rock, so as to polish it and leave it indented with parallel scratches and grooves,—such markings as are still visible in the rocks of Scandinavia, Scotland, Canada, and many other countries.

There can be no doubt that the myriads of angular and rounded blocks above alluded to cannot have been borne along by ordinary rivers or marine currents, so great is their volume and weight, and so clear are the signs, in many places, of time having been occupied in their successive deposition; for while some of them are buried in mud and sand, others are distributed at various depths through heaps of regularly stratified sand and gravel. No waves of the sea raised by earthquakes, nor the bursting of lakes dammed up for a time by landslips or by avalanches of snow, can account for the observed facts; but I shall endeavour to show, in the sequel,* that a combination of existing causes may have conveyed erratics into their present situations.

* See also Elements of Geology, ch. 11, 12, and Student's Elements, p. 143; et seq.

The causes which will be referred to are, first, the carrying power of ice, combined with that of running water; and second, the upward movement of the bed of the sea, converting it gradually into land. Without entering at present into any details respecting these causes, I may mention that the transportation of blocks by ice is now simultaneously in progress, not only in the arctic and antarctic regions, but in a part of the temperate latitudes both of the northern and southern hemispheres, as, for example, on the coasts of Canada and Gulf of St. Lawrence, and also in Chili, Patagonia, and the island of South Georgia. In those regions the uneven bed of the ocean is becoming strewed over with ice-drifted fragments, which have either stranded on shoals, or been dropped in deep water by melting bergs. The entanglement of boulders in drift ice will also be shown to occur annually in North America, and these stones, when firmly frozen into ice, wander year after year from Labrador to the St. Lawrence, and reach points of the western hemisphere farther south than any part of Great Britain.

The general absence of erratics in the warmer parts of the equatorial regions of Asia, Africa, and America, confirms the same views. As to the polishing and grooving of hard rocks, it has been ascertained that glaciers give rise to these effects when pushing forward sand, pebbles, and rocky fragments, and causing them to grate along the bottom. Nor can there be any reasonable doubt that icebergs, when they run aground on the floor of the ocean, must imprint somewhat similar marks upon it.

It is unnecessary, therefore, to refer to deluges, or great oceanic waves, to explain the transportation of erratics to great distances.

As to variations in the tides in past times, they can never have been sufficient to have imparted to marine currents, or to the waves breaking on a coast, a degree of force greatly exceeding that which they usually exert. When the excentricity of the earth's orbit, of which more will be said in the thirteenth chapter, is at or near its maximum, the rise of the solar tide will amount to two-and-a-half instead of two feet; but the increased power thus derived

from solar attraction may be neglected by a geologist, seeing that the configuration of the land now produces differences in the height of the tides to the extent of fifty feet and upwards, instead of those few additional inches gained by proximity to the sun in the case above proposed. At some former periods, as we shall afterwards see, the local development of ice, sometimes in one hemisphere, sometimes in the other, was so great as to enable it to exert a carrying power far beyond what it now exerts in the same region. But such increased ice-action, recurring at distant intervals and for limited periods, is by no means confirmatory of the theory of those who ascribe paroxysmal energy to causes supposed to have operated in a nascent state of the planet. In regard also to ice, we must remember that its action on land is substituted for that of running water. The one becomes a mighty agent in transporting huge erratics, and in scoring, abrading, and polishing rocks, but meanwhile the other is in abeyance. When, for example, the ancient Rhone glacier conveyed its moraines from the upper to the lower end of the Lake of Geneva, there was no great river as there now is, forming a delta many miles in extent, and several hundred feet in depth, at the upper end of the lake.

Deluges.—As deluges have been often alluded to (page 10, &c.), I shall say something of the causes which may be supposed to give rise to these grand movements of water.

Geologists who believe that mountain-chains have been thrown up suddenly at many successive epochs, imagine that the waters of the ocean may be raised by these convulsions, and then break in terrific waves upon the land, sweeping over whole continents, hollowing out valleys, and transporting sand, gravel, and erratics to great distances. The sudden rise of the Alps or Andes, it is said, may have produced a flood even subsequently to the time when the earth became the residence of man. But it seems strange that none of the writers who have indulged their imagination in conjectures of this kind should have ascribed a deluge to the sudden conversion of part of the unfathomable ocean into a shoal rather than to the rise of mountain-chains. In the latter case the mountains themselves could do no

more than displace a certain quantity of atmospheric air, whereas the instantaneous formation of the shoal would displace a vast body of water, which being heaved up to a great height might roll over and submerge a large portion of a continent.

If we restrict ourselves to combinations of causes at present known, it would seem that the two principal sources of extraordinary inundations are, first the escape of the waters of a large lake raised far above the sea; and, secondly, the pouring down of a marine current into lands depressed below the mean level of the ocean.

As an example of the first of these cases, we may take Lake Superior, which is more than 400 geographical miles in length, and about 150 in breadth, having an average depth of from 500 to 900 feet. The surface of this vast body of fresh water is no less than 600 feet above the level of the ocean; the lowest part of the barrier which separates the lake on its south-west side from those streams which flow into the head waters of the Mississippi being about 600 feet high. If, therefore, a series of subsidences should lower any part of this barrier, even a few yards at a time, or if earthquakes should rend it open, the breaches thus made might allow the sudden escape of vast floods of water into a hydrographical basin of enormous extent. If the event happened in the dry season, when the ordinary channels of the Mississippi and its tributaries are in a great degree empty, the inundation might not be considerable; but if in the flood season, a region capable of supporting a population of many millions might be suddenly submerged. But even this event would be insufficient to cause a violent rush of water, and to produce those effects usually called diluvial; for the difference of level of 600 feet between Lake Superior and the Gulf of Mexico, when distributed over a distance of 1,800 miles, would give an average fall of only four inches per mile.

The second case before adverted to is where there are large tracts of dry land beneath the mean level of the ocean. It seems, after much controversy, to be at length a settled point, that the Caspian is really 83 feet 6 inches lower than the Black Sea. As the Caspian covers an area about equal

to that of Spain, and as its shores are in general low and flat, there must be many thousand square miles of country less than 83 feet above the level of that inland sea, and consequently depressed below the Black Sea and Mediterranean. This area includes the site of the populous city of Astrakhan and other towns. Into this region the ocean would pour its waters, if the land now intervening between the Black Sea (or rather the Sea of Azof) and the Caspian should subside. Yet, even if this event should occur, it is most probable that the submergence of the whole region would not be accomplished simultaneously, but by a series of minor floods, the sinking of the barrier being gradual.* The shores of the Dead Sea have lately been ascertained by a party of our Royal Engineers to be about 1,300 English feet below the level of the Mediterranean, or about four feet less than 1,300 on an average.† In this case, towns built on hills nearly 1,300 feet high might be submerged by such a change of level in the barrier as would open a communication between the Mediterranean and the valley of the Jordan.

Supposed universality of ancient deposits.—The next fallacy which has helped to perpetuate the doctrine that the operations of water were on a different and grander scale in ancient times is founded on the indefinite areas over which homogeneous deposits were supposed to extend. No modern sedimentary strata, it was said, equally identical in mineral character and fossil contents, can be traced continuously from one quarter of the globe to another. But the first propagators of these opinions were very slightly acquainted with the inconstancy in mineral composition of the ancient

* It has been suspected ever since the middle of the last century, that the Caspian was lower than the ocean, it being known that in Astrakhan the mercury in the barometer generally stands above thirty inches. In 1836, the Russian government directed the Academy of St. Petersburg to send an expedition to determine the relative level of the Caspian and Black Seas by a trigonometrical survey. It was found that the Caspian was 101 Russian, or 108 English, feet lower than the Black Sea. (For authorities, see Journ. Roy. Geograph. Soc. vol. viii. p. 135.) Sir R. Murchison, however, concludes, in 1845, from the best Russian authorities, that the depression of the Caspian is only 83 feet 6 inches.

† Sir Henry James, who planned this survey, which was executed by Capt. Wilson, R.E., informs me that on the 12th of March, 1865, the difference of level was 1,292 feet. The maximum depression occurring in the dry season amounts to 1,298 feet, the minimum, as ascertained by the drifted seaweed on the shores, being only 1,289·5 feet.

formations, and equally so of the wide spaces over which the same kind of sediment is now actually distributed by rivers and currents in the course of centuries. The persistency of character in the older series was exaggerated, its extreme variability in the newer was assumed without proof. In the chapter which treats of river-deltas and the dispersion of sediment by currents, and in the description of reefs of coral now growing over areas many hundred miles in length, I shall have opportunities of convincing the reader of the danger of hasty generalisations on this head. I may also mention in this place, that the vast distance to which the white chalk can be traced east and west over Europe, as well as north and south, from Denmark to the Crimea, seemed to some geologists a phenomenon, to which the working of causes now in action could present no parallel. But the soundings made in the Atlantic for the submarine telegraph have taught us that white mud, formed of organic bodies very similar to those of the ancient chalk, is in progress over spaces still more vast.*

But in regard to the imagined universality of particular rocks of ancient date, it was almost unavoidable that this notion, when once embraced, should be perpetuated; for the same kinds of rock have occasionally been reproduced at successive epochs: and when once the agreement or disagreement in mineral character alone was relied on as the test of age, it followed that similar rocks, if found even at the antipodes, were referred to the same era, until the contrary could be shown.

Now it is usually impossible to combat such an assumption on geological grounds, so long as we are imperfectly acquainted with the order of superposition and the organic remains of these same formations. Thus, for example, the red marl and red sandstone, containing salt and gypsum (the Triassic group of the table, p. 135), being interposed in England between the Lias and the Coal, all other red marls and sandstones, associated some of them with salt, and others with gypsum, and occurring not only in different parts of Europe, but in North America, Peru, India, and salt deserts of Asia,

* Elements of Geol., 6th edit. p. 318; and Student's Elements, p. 261.

those of Africa—in a word, in every quarter of the globe—were referred to one and the same period. The burden of proof was not supposed to rest with those who insisted on the identity in age of all these groups—their identity in mineral composition was thought sufficient. It was in vain to urge as an objection the improbability of the hypothesis which implies that all the moving waters on the globe were once simultaneously charged with sediment of a red colour.

But the rashness of pretending to identify, in age, all the red sandstones and marls in question, has at length been sufficiently exposed, by the discovery that, even in Europe, they belong decidedly to many different epochs. The investigations of De Verneuil in Spain have shown that the red sandstone and red marl, containing the rock salt of Cardona in Catalonia, belong to the Middle Eocene or Nummulitic period. It is also known that certain red marls and variegated sandstones in Auvergne which are undistinguishable in mineral composition from the New Red Sandstone of English geologists, are nevertheless of the same older tertiary period: and, lastly, the gypseous red marl of Aix, in Provence, formerly supposed to be a marine secondary group, is now acknowledged to be a tertiary fresh-water formation. In Nova Scotia one great deposit of red marl, sandstone, and gypsum, precisely resembling in mineral character the 'New Red' of England, occurs as a member of the Carboniferous group, and in the United States near the Falls of Niagara, a similar formation constitutes a subdivision of the Upper Silurian series.*

Nor was the nomenclature commonly adopted in geology without its influence in perpetuating the erroneous doctrine of universal formations. Such names, for example, as Chalk, Greensand, Oolite, Red Marl, Coal, and others, were given to some of the principal fossiliferous groups in consequence of mineral peculiarities which happened to characterise them in the countries where they were first studied. When geologists had at length shown, by means of fossils and the order of superposition, that other strata, entirely dissimilar in colour, texture, and composition, were of contemporaneous

* See Lyell's Travels in N. America, ch. 2 and 25.

date, it was thought convenient still to retain the old names. That these were often inappropriate was admitted; but the student was taught to understand them in no other than a chronological sense; so that the Chalk might be a grey quartzose sandstone devoid of calcareous matter, as near Dresden, or a hard, compact, and sometimes flaggy limestone, as in parts of the Alps, or a brown sandstone or green marl, as in New Jersey, U.S. In like manner, the Greensand, it was said, is often represented by limestone and other mineral masses entirely devoid of green grains. So the Oolitic texture was declared to be rather an exception than otherwise to the general rule in rocks of the Oolitic period, and to be found in strata both of older and newer date; and it often became necessary to affirm that no particle of carbonaceous matter could be detected in districts where the true Coal series abounded. In spite of every precaution, the habitual use of this language could scarcely fail to instil into the mind of the pupil an idea that chalk, coal, salt, red marl, and the Oolitic structure were far more widely characteristic of the rocks of a given age than was really the case.

There is still another cause of deception, disposing us to ascribe a more limited range to the newer sedimentary formations as compared to the older, namely, the very general concealment of the newer strata beneath the waters of lakes and seas, and the wide exposure above waters of the more ancient. The Chalk, for example, now seen stretching for thousands of miles over different parts of Europe, has become visible to us by the effect, not of one, but of many distinct series of subterranean movements. Time has been required, and a succession of geological periods, to raise it above the waves in so many regions; and if calcareous rocks of the middle and upper tertiary periods have been formed, as homogeneous in mineral composition throughout equally extensive regions, it may require convulsions as numerous as all those which have occurred since the origin of the Chalk to bring them up within the sphere of human observation. Hence the rocks of more modern periods may appear partial, as compared to those of remoter eras, not because of any original inferiority in their extent, but because there has not

been sufficient time since their origin for the development of a great series of elevatory movements.

In regard, however, to one of the most important characteristics of sedimentary rocks, their organic remains, many naturalists of high authority have maintained that the same species of fossils are more widely distributed through formations of high antiquity than in those of more modern date, and that distinct zoological and botanical provinces, as they are called, which form so striking a feature in the living creation, were not established at remote eras. Thus the plants of the Coal, the shells and trilobites of the Silurian rocks, and the ammonites of the Oolite, have been supposed to have a wider geographical range than any living species of plants, crustaceans, or mollusks. This opinion seems in certain cases to be well founded, especially in relation to the plants of the Carboniferous epoch, owing partly to greater uniformity of climate, and partly, as Professor Heer has suggested, to the fact that almost all the plants—including even large trees—of that period, were cryptogamous: so that their minute spores might be carried by the wind for indefinite distances, as are now the spores of ferns, mosses, and lichens. But a recent comparison of the fossils of North American rocks with those of corresponding ages in the European series, has proved that the terrestrial vegetation of the Carboniferous epoch is an exception to the general rule, and that the fauna and flora of the earth at successive periods, from the oldest Silurian to the newest Tertiary, were as diversified as now. The shells, corals, and other classes of organic remains demonstrate the fact that the earth might then have been divided into separate zoological provinces, in a manner analogous to that observed in the geographical distribution of species now living.

CHAPTER VII.

ON THE SUPPOSED FORMER INTENSITY OF THE IGNEOUS FORCES.

VOLCANIC ACTION AT SUCCESSIVE GEOLOGICAL PERIODS—PLUTONIC ROCKS OF DIFFERENT AGES—GRADUAL DEVELOPMENT OF SUBTERRANEAN MOVEMENTS—FAULTS—DOCTRINE OF THE SUDDEN UPHEAVAL OF PARALLEL MOUNTAIN-CHAINS—OBJECTIONS TO THE PROOF OF THE SUDDENNESS OF THE UPHEAVAL, AND THE CONTEMPORANEOUSNESS OF PARALLEL CHAINS—TRAINS OF ACTIVE VOLCANOS NOT PARALLEL—AS LARGE TRACTS OF LAND ARE RISING OR SINKING SLOWLY, SO NARROW ZONES OF LAND MAY BE PUSHED UP GRADUALLY TO GREAT HEIGHTS—BENDING OF STRATA BY LATERAL PRESSURE—ADEQUACY OF THE VOLCANIC POWER TO EFFECT THIS WITHOUT PAROXYSMAL CONVULSIONS.

When reasoning on the intensity of volcanic action at former periods, as well as on the power of moving water, geologists have been ever prone to represent Nature as having been prodigal of violence and parsimonious of time. Now, although it is less easy to determine the relative ages of the volcanic than of the fossiliferous formations, it is undeniable that igneous rocks have been produced at all geological periods, or as often as we find distinct deposits marked by peculiar animal and vegetable remains. It can be shown, for example, that there are not only trappean rocks contemporaneous with the Palæozoic, Mesozoic, and Cainozoic periods, and with each of the several groups into which these are divisible, but that volcanic products can be more strictly limited and assigned to minor subdivisions, such as the Lower and Upper Carboniferous and the Lower and Upper Eocene. Again, if one of these igneous formations is examined in detail, we find it to be the product of many successive ejections or outpourings of volcanic matter.* As we enlarge,

* See Elements of Geology, 6th ed.; and Student's Elements, 1871. Index, 'Volcanic.'

therefore, our knowledge of the ancient rocks formed by subterranean heat, we find ourselves compelled to regard them as the aggregate effects of innumerable eruptions, each of which may not have exceeded in violence those now experienced in volcanic regions.

It may indeed be said that we have as yet no data for estimating the relative volume of matter simultaneously in a state of fusion at two given periods, such as enable us for instance to compare the columnar basalt of Staffa and its environs with the lava poured out in Iceland in 1783; and for this very reason it would be rash and unphilosophical to assume an excess of ancient as contrasted with modern outpourings of melted matter at particular periods of time.* It would be still more presumptuous to take for granted that the more deep-seated effects of subterranean heat surpassed at remote eras the corresponding effects of internal heat in our own times. Certain porphyries and granites, and all the rocks commonly called plutonic, are now generally supposed to have resulted from the slow cooling of materials fused and solidified under great pressure; and we cannot doubt that beneath existing volcanos there are large spaces filled with melted stone, which must for centuries remain in an incandescent state, and then cool and become hard and crystalline. That lakes of lava are continuous for hundreds of miles beneath the Chilian Andes, seems established by observations made in the year 1835.†

Now, wherever the fluid contents of such reservoirs are poured out successively from craters in the open air, or at the bottom of the sea, the matter so ejected may afford evidence by its arrangement of having originated at different periods; but if the subterranean residue after the withdrawal of the heat be converted into crystalline or plutonic rock, the entire mass may seem to have been formed at once, however countless the ages required for its fusion and subsequent refrigeration. As the idea that all the granite in the earth's crust was produced simultaneously, and in a primitive state of the planet, has now been universally abandoned; so the

* See below, vol. ii., Icelandic eruptions.

† See below, vol. ii., Chilian earthquake.

suggestion above adverted to may put us on our guard against too readily adopting another opinion, namely, that each large mass of granite was generated in a brief period of time. Modern writers of authority indeed seem more and more agreed that in the case of granitic rocks, the passage from a liquid or pasty to a solid and crystalline state must have been an extremely gradual process.

The doctrine so much insisted upon formerly, that crystalline rocks, such as granite, gneiss, mica-schist, quartzite, and others, were produced in the greatest abundance in the earlier ages of the planet, and that their formation has ceased altogether in our own times, will be controverted in the next chapter.

Gradual development of subterranean movements.—The extreme violence of the subterranean forces in remote ages has been often inferred from the fact that the older rocks are more fractured and dislocated than the newer. But what other result could we have anticipated if the quantity of movement had been always equal in equal periods of time? Time must, in that case, multiply the derangement of strata in the ratio of their antiquity. Indeed the numerous exceptions to the above rule which we find in nature, present at first sight the only objection to the hypothesis of uniformity. For the more ancient formations remain in many places horizontal, while in others much newer strata are curved and vertical. This apparent anomaly, however, will be seen in the next chapter to depend on the irregular manner in which the volcanic and subterranean agencies affect different parts of the earth in succession, being often renewed again and again in certain areas, while others remain during the whole time at rest.

That the more impressive effects of subterranean power, such as the upheaval of mountain-chains, may have been due to multiplied convulsions of moderate intensity rather than to a few paroxysmal explosions, will appear the less improbable when the gradual and intermittent development of volcanic eruptions in times past is once established, for geologists no longer doubt that there is an intimate connection between the two classes of phenomena.

Faults.—The same reasoning is applicable to great *faults*, or those striking instances of the upthrow or downthrow of large masses of rock, which have been thought by some to imply tremendous catastrophes wholly foreign to the ordinary course of nature. Thus we have in England faults in which the vertical displacement of the rocks amounts sometimes to several hundred, and in other cases to several thousand feet, while the line of fissure extends horizontally for distances varying from a few hundred yards to thirty miles. Their width varies from less than an inch to fifty feet, the space between the opposite walls being now filled up with fragmentary matter from the sides, and various minerals which have crystallised along the fissures. But when we enquire into the proofs of the mass having risen or fallen suddenly on the one side of these great rents, several hundreds or thousands of feet above or below the rock with which it was once continuous on the other side, we find the evidence defective. There are grooves, it is said, and scratches on the rubbed and polished walls which have often one common direction, favouring the theory that the movement was accomplished by a single stroke, and not by a series of interrupted movements. But, in fact, the striæ are not always parallel in such cases, but often irregular, and sometimes the stones and earth which are in the middle of the fault, or fissure, have been polished and striated by friction in different directions, showing that there have been slidings subsequent to the first introduction of the fragmentary matter. Nor should we forget that the last movement must always tend to obliterate the signs of previous trituration, so that neither its instantaneousness nor the uniformity of its direction can be inferred from the parallelism of the striæ that have been last produced.

When rocks have been once fractured, and freedom of motion communicated to detached portions of them, these will naturally continue to yield in the same direction, if the process of upheaval or of undermining be repeated again and again. The incumbent mass will always give way along the lines of least resistance, and therefore usually in the places where it was formerly rent asunder. Probably the effects of

reiterated movement, whether upward or downward, in a fault, may be undistinguishable from those of a single and instantaneous rise or subsidence; and the same may be said of the rising or falling of continental masses, such as Sweden or Greenland, which we know to take place slowly and insensibly.

Doctrine of the sudden upheaval of parallel mountain-chains.—The doctrine of the suddenness of many former revolutions in the physical geography of the globe has been thought by some to derive additional confirmation from a theory respecting the origin of mountain-chains, advanced in 1833 by a distinguished geologist, M. Elie de Beaumont. In several essays on this subject, the last published in 1852, he has attempted to establish two points; first, that a variety of independent chains of mountains have been thrown up suddenly at particular periods; and, secondly, that the contemporaneous chains thus thrown up preserve a parallelism the one to the other.

These opinions, and others by which they are accompanied, are so adverse to the method of interpreting the history of geological changes which I have recommended in this work, that I am desirous of explaining the grounds of my dissent, a course which I feel myself the more called upon to adopt, as the generalisations alluded to have been very popular, owing to the known experience of the author as an observer in the field, his profound mathematical acquirements, and his skill as a writer. I shall begin, therefore, by giving a brief summary of the principal propositions laid down in the works above referred to.*

1st. M. de Beaumont supposes 'that in the history of the earth there have been long periods of comparative repose, during which the deposition of sedimentary matter has gone on in regular continuity; and there have also been short periods of paroxysmal violence, during which that continuity was broken.

* Ann. des Sci. nat., septembre, novembre, et décembre 1829. Revue française, No. 15. May 1830. Bulletin de la Société Géol. de France, p. 864. May 1847. The latest edition of M. de Beaumont's theory will be found in the 12th vol. of the Dictionnaire universelle d'Hist. nat. 1852, art. 'Systèmes de Montagnes;' also the same printed separately.

'2dly. At each of these periods of violence or "revolution," in the state of the earth's surface, a great number of mountain-chains have been formed suddenly.

'3dly. The chains thrown up by a particular revolution have one uniform direction, being parallel to each other within a few degrees of the compass, even when situated in remote regions; whilst the chains thrown up at different periods differ, for the most part, from each other in direction.

'4thly. Each "revolution," or "great convulsion," has fallen in with the date of another geological phenomenon; namely, "the passage from one independent sedimentary formation to another," characterised by a considerable difference in "organic types."

'5thly. There has been a recurrence of these paroxysmal movements from the remotest geological periods; and they may still be reproduced, and the repose in which we live may hereafter be broken by the sudden upthrow of another system of parallel chains of mountains.

'6thly. The origin of these chains depends not on partial volcanic action, or a reiteration of ordinary earthquakes, but on the secular refrigeration of the entire planet. For the whole globe, with the exception of a thin envelope, much thinner in proportion than the shell to an egg, is a fused mass, kept fluid by heat, but constantly cooling and contracting its dimensions. The external crust does not gradually collapse and accommodate itself century after century to the shrunken nucleus, subsiding as often as there is a slight failure of support, but it is sustained throughout whole geological periods, so as to become partially separated from the nucleus, until at last it gives way suddenly, cracking and falling in along determinate lines of fracture. During such a crisis the rocks are subjected to great lateral pressure, the unyielding ones are crushed, and the pliant strata bent, and are forced to pack themselves more closely into a smaller space, having no longer the same room to spread themselves out horizontally. At the same time, a large portion of the mass is squeezed upwards, because it is in the upward direction only that the excess in size of the envelope, as compared to the contracted nucleus, can find relief. This excess

produces one or more of those folds or wrinkles in the earth's crust which we call mountain-chains.

'Lastly, some chains are comparatively modern; such as the Alps, which were partly upheaved after the middle tertiary period. The elevation of the Andes was much more recent, and was accompanied by the simultaneous outburst for the first time of 270 of the principal volcanos now active.* The agitation of the waters of the ocean caused by this convulsion probably occasioned that transient and general deluge which is noticed in the traditions of so many nations.' †

Several of the topics enumerated in the above summary, such as the cause of interruptions in the sedimentary series, will be discussed in the 14th chapter, and I shall now confine myself to what I conceive to be the insufficiency of the proofs adduced in favour of the suddenness of the upthrow, and the contemporaneousness of the origin of the parallel chains referred to. At the same time I may remark, that the great body of facts collected together by M. de Beaumont will always form a most valuable addition to our knowledge, tending as they do to confirm the doctrine that different mountain-chains have been formed in succession, and, as Werner first pointed out, that there are certain determinate lines of direction or strike in the strata of various countries.

The following may serve as an analysis of the evidence on which the theory above stated depends. 'We observe,' says M. de Beaumont, 'when we attentively examine nearly all mountain-chains, that the most recent rocks extend horizontally up to the foot of such chains, as we should expect would be the case if they were deposited in seas or lakes, of which these mountains have partly formed the shores; whilst the other sedimentary beds, tilted up, and more or less contorted, on the flanks of the mountains, rise in certain points even to their highest crests.' ‡ There are, therefore, in and adjacent to each chain, two classes of sedimentary rocks, the ancient or inclined beds, and the newer or horizontal. It is evident that the first appearance of the chain itself was an

* Systèmes de Montagnes, p. 762.

† Ibid. pp. 761 and 773.

‡ Phil. Mag. and Annals, No. 58. New Series, p. 242.

event 'intermediate between the period when the beds now upraised were deposited, and the period when the strata were produced horizontally at its feet.'

Thus the chain A assumed its present position after the

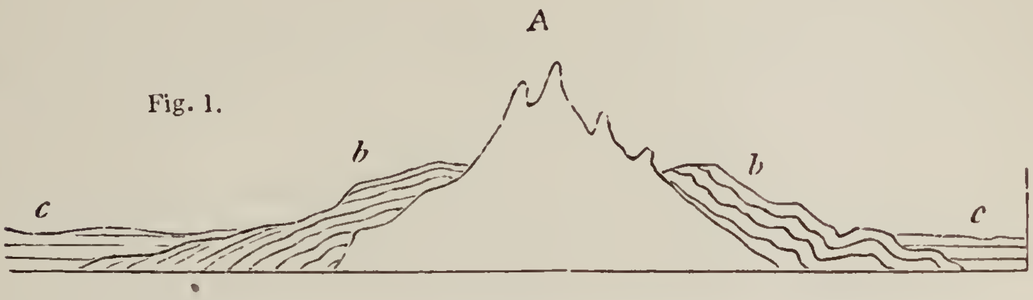


Fig. 1.

deposition of the strata *b*, which have undergone great movements, and before the deposition of the group *c*, in which the strata have not suffered derangement.

If we then discover another chain B, in which we find not

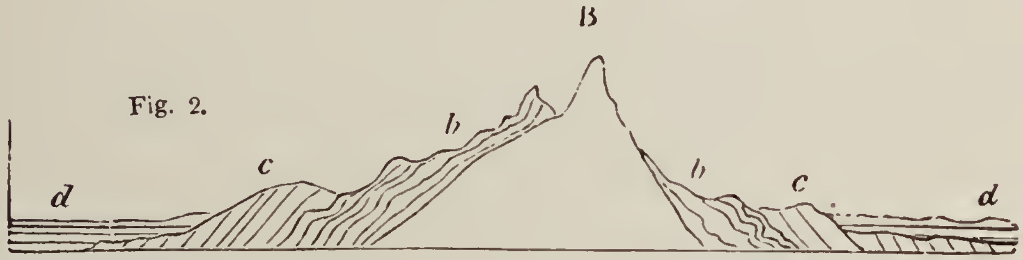


Fig. 2.

only the formation *b*, but the group *c* also, disturbed and thrown on its edges, we may infer that the latter chain is of subsequent date to A; for B must have been elevated *after* the deposition of *c*, and before that of the group *d*; whereas A had originated *before* the strata *c* were formed.

It is then argued, that in order to ascertain whether other mountain-ranges are of contemporaneous date with A and B, or are referable to *distinct* periods, we have only to enquire whether the inclined and undisturbed sets of strata in each range correspond with or differ from those in the typical chains A and B.

Now all this reasoning is perfectly correct so long as the period of time required for the deposition of the strata *b* and *c* respectively is not made identical in duration with the period of time during which the animals and plants found fossil in *b* and *c* may have flourished; for the duration of certain groups of species may have greatly exceeded, and probably did greatly exceed, the time required for the

accumulation of certain local deposits, such as *b* and *c* (figs. 1 and 2). In order, moreover, to render the reasoning correct, due latitude must be given to the term contemporaneous; for this term must be understood to allude, not to a moment of time, but to the interval, whether brief or protracted, which elapsed between two events, namely, between the accumulation of the inclined and that of the horizontal strata.

But, unfortunately, no attempt has been made in the treatises under review to avoid this manifest source of confusion, and hence the very terms of each proposition are equivocal; and the possible length of some of the intervals is so vast, that to affirm that all the chains raised in such intervals were *contemporaneous* is an abuse of language.

In order to illustrate this argument, I shall select the Pyrenees as an example. Originally M. E. de Beaumont spoke of this range of mountains as having been uplifted suddenly (*à un seul jet*), but he has since conceded that in this chain, in spite of the general unity and simplicity of its structure, six, if not seven, systems of dislocation of different dates can be recognised.* In reference, however, to the latest, and by far the most important of these convulsions, the chain is said to have attained its present elevation at a certain epoch in the earth's history, namely, between the deposition of the chalk, or rocks of about that age, and that of certain tertiary formations 'as old as the plastic clay;' for the chalk is seen in vertical, curved, and distorted beds on the flanks of the chain, as the beds *b*, fig. 1, while the tertiary formations rest upon them in horizontal strata at its base, as *c*, ibid.

The proof, then, of the extreme suddenness of the convulsion is supposed to be the shortness of the time which intervened between the formation of the chalk and the origin of certain tertiary strata.† Even if the interval were reducible within these limits, it might comprise an indefinite lapse of time. In strictness of reasoning, however, the author cannot exclude the Cretaceous or the Tertiary periods

* Systèmes de Montagnes, 1852, p. 429.

† Phil. Mag. and Annals, No. 58. New Series, p. 243.

from the possible duration of the interval during which the elevation may have taken place, for, in the first place, it cannot be assumed that the movement of upheaval took place after the close of the Cretaceous period; we can merely say, that it occurred after the deposition of certain strata of that period; secondly, although it were true that the event happened before the formation of all the tertiary strata now at the base of the Pyrenees, it would by no means follow that it preceded the whole Tertiary epoch.

The age of the strata, both of the inclined and horizontal series, may have been accurately determined by M. de Beaumont, and still the upheaving of the Pyrenees may have been going on before the animals of the Chalk period, such as are found fossil in England, had ceased to exist, or when the Maestricht beds were in progress, or during the indefinite ages which may have elapsed between the extinction of the Maestricht animals and the introduction of the Eocene tribes, or during the Eocene epoch, or the rise may have been going on throughout one, or several, or all of these periods.

It would be a purely gratuitous assumption to say that the inclined cretaceous strata (*b*, fig. 1) on the flanks of the Pyrenees, were the very last which were deposited during the Cretaceous period, or that as soon as they were upheaved all or nearly all the species of animals and plants now found fossil in them were suddenly exterminated; yet, unless this can be affirmed, we cannot say that the Pyrenees were not upheaved during the Cretaceous period. Consequently, another range of mountains, at the base of which cretaceous rocks may lie in horizontal stratification, may have been elevated, like the chain A, fig. 1, during some part of the same great period.

There are mountains in Sicily two or three thousand feet high, the tops of which are composed of limestone, in which a large proportion of the fossil shells agree specifically with those now inhabiting the Mediterranean. Here, as in many other countries, the deposits now in progress in the sea must inclose shells and other fossils specifically identical with those of the rocks constituting the contiguous land. So

there are islands in the Pacific, where a mass of dead coral has emerged to a considerable altitude, while other portions of the mass remain beneath the sea, still increasing by the growth of living zoophytes and shells. The chalk of the Pyrenees, therefore, may at a remote period have been raised to an elevation of several thousand feet, while the species found fossil in the same chalk still continued to be represented in the fauna of the neighbouring ocean. In a word, we cannot assume that the origin of a new range of mountains caused the Cretaceous period to cease, and served as the prelude to a new order of things in the animate creation.

To illustrate the grave objections above advanced, against the theory considered in the present chapter, let us suppose, that in some country three styles of architecture had prevailed in succession, each for a period of one thousand years; first the Greek, then the Roman, and then the Gothic; and that a tremendous earthquake was known to have occurred in the same district during one of the three periods—a convulsion of such violence as to have levelled to the ground all the buildings then standing. If an antiquary, desirous of discovering the date of the catastrophe, should first arrive at a city where several Greek temples were lying in ruins and half engulphed in the earth, while many Gothic edifices were standing uninjured, could he determine on these data the era of the shock? Could he even exclude any one of the three periods, and decide that it must have happened during one of the other two? Certainly not. He could merely affirm that it happened at some period after the introduction of the Greek style, and before the Gothic had fallen into disuse. Should he pretend to define the date of the convulsion with greater precision, and decide that the earthquake must have occurred after the Greek and before the Gothic period, that is to say, when the Roman style was in use, the fallacy in his reasoning would be too palpable to escape detection for a moment.

Yet such is the nature of the erroneous induction of which I am now treating. For as, in the example above proposed, the erection of a particular edifice is an event scarcely ever coextensive in time with the whole period of a certain style

of architecture to which it conformed, so the deposition of chalk or any other set of strata may have been effected in a small part of that geological epoch to which the species of fossils characterising such strata may belong.

It is almost superfluous to enter into any further analysis of the theory of parallelism, because the whole force of the argument depends on the accuracy of the data by which the contemporaneous or non-contemporaneous date of the elevation of two independent chains can be demonstrated. In every case, this evidence, as stated by M. de Beaumont, is equivocal, because he has not included in the possible interval of time between the deposition of the deranged and the horizontal formations, part of the periods to which each of those classes of formations are referable. Even if all the geological facts, therefore, adduced by the author were true and unquestionable, yet the conclusion that certain chains were or were not simultaneously upraised is by no means a legitimate consequence.

In the third volume of my first edition of the Principles, which appeared in April 1833, I controverted the views of M. de Beaumont, then just published, in the same terms as I have now restated them. At that time I took for granted that the chronological date of the newest rocks entering into the disturbed series of the Pyrenees had been correctly ascertained. It now appears, however, that some of the most modern of those disturbed strata belong to the nummulitic formation, which are now regarded by the majority of geologists as Eocene or lower tertiary.

Perhaps a more striking illustration of the difficulties we encounter, when we attempt to apply the theory under consideration even to the best known European countries, is afforded by what is called by de Beaumont 'The System of the Longmynds.' This small chain, situated in Shropshire, and having a direction of N. 25° E., is the third of the typical systems to which other mountain-ranges corresponding in *strike* and structure are compared. The date assigned to its upheaval is 'after the unfossiliferous greywacke, or Cambrian strata, and before the Silurian.' But Sir R. I. Murchison had shown in 1838, in his 'Silurian System,' and the British

Government surveyors, since that time, in their sections (about 1845), that the Longmynds and other chains of similar composition in North Wales were elevated in *post-Silurian* times. In all of them fossiliferous beds of the lower Silurian formation or Llandeilo flags are highly inclined, and often vertical. When, therefore, so grave an error is detected in regard to the age of a typical chain, we are entitled to enquire with surprise, by what means nine other *parallel* chains in France, Germany, and Sweden, assumed to be 'ante-Silurian,' have been made to agree precisely in date of upheaval with the Longmynds? If they are correctly represented as older than the Silurian strata, they cannot be contemporaneous with the Longmynds, and this only proves how little reliance can be placed on parallelism as a test of simultaneousness of upheaval. But in truth it is impossible, for reasons already given, to demonstrate that each of those nine chains coincide in date with one another, any more than with the Longmynds.

It will be seen in the second volume* that various opinions are entertained as to the minimum thickness which may with probability be assigned to the solid crust of the earth. According to some calculations it cannot be less than 800 or 1000 miles thick, and may be more. Even if it be solid to the depth of a hundred miles, such a thickness would be inconsistent with M. E. de Beaumont's hypothesis, which requires a shell not more than thirty miles thick, or even less. But it is not denied by those who insist on the solidity of the exterior of the planet to a great depth that, though solid as a whole, it may contain within it vast lakes or seas of lava. If so, the gradual fusion of rocks, and the expansive power of heat exerted for ages, as well as the subsequent contraction of the same during slow refrigeration, may have much to do with those movements of upheaval and subsidence which give origin to mountain-chains. For these, as Dolomieu has remarked, are 'far less important, proportionally speaking, than the inequalities on the surface of an egg-shell, which to the eye appears smooth.' A 'centripetal

* See Index, 'Earth, crust of.'

force' affecting the whole planet as it cools, seems a mightier cause than is required to produce wrinkles of such insignificant size.

In pursuing his investigations, M. E. de Beaumont has of late greatly multiplied the number of successive periods of instantaneous upheaval, admitting at the same time that occasionally new lines of upthrow have taken the direction of older ones.* These admissions render his views much more in harmony with the principles advocated in this work, but they impair the practical utility of parallelism, considered as a chronological test; for no rule is laid down for limiting the interval, whether in time or space, which may separate two parallel lines of upheaval of different dates.† In his later enquiries he has come to the conclusion, that the principal mountain-ranges, if prolonged, would intersect each other at certain angles, so as to produce a regular geometric arrangement, which he calls a 'pentagonal network.' This theory has been ably discussed and controverted by Mr. Hopkins.‡

Among the various propositions above laid down (p. 120), it will be seen that the sudden rise of the Andes is spoken of as a modern event, but Mr. Darwin, in his Geology of South America, has brought together ample data in proof of the local persistency of volcanic action throughout a long succession of geological periods, beginning with times antecedent to the deposition of the oolitic and cretaceous formations of Chili, and continuing to the historical epoch. It appears that some of the parallel ridges which compose the Cordilleras, instead of being contemporaneous, were successively and slowly upheaved at widely different epochs. The whole range, after twice subsiding some thousands of feet, was brought up again by a slow movement in mass, during the era of the Eocene tertiary formations, after which the whole sank down once more several hundred feet, to be again uplifted to its present level by a slow and often interrupted movement.§

* Art. Systèmes de Montagnes, p. 775.

† Comptes Rendus, Sept. 1850, and Systèmes de Montagnes.

‡ Anniversary Address as President of the Geol. Soc., Feb. 1853.

§ Darwin's Geology of South America, p. 248. London, 1846.

In a portion of this latter period the 'Pampean mud' was formed, in which the Megatherium, Mylodon, and other extinct quadrupeds are buried. This mud contains in it recent species of shells, some of them proper to brackish water, and is believed by Mr. Darwin to be an estuary or delta deposit.

In studying many chains of mountains, we find that the strike or line of outcrop of continuous sets of strata, and the general direction of the chain, may be far from rectilinear. It may even deviate from the normal direction at an angle of 20° or 30°, as is exemplified in the Alleghanies.* In like manner, trains of active volcanos and the zones throughout which modern earthquakes occur are often linear, but though contemporaneous, all belonging to our own epoch, they are not by any means parallel, but some at right angles, the one to the other.

Slow upheaval and subsidence.—Recent observations have disclosed to us the wonderful fact, that not only the west coast of South America, but also other large areas, some of them several thousand miles in circumference, such as Scandinavia, and certain archipelagos in the Pacific, are slowly and insensibly rising; while other regions, such as Greenland, and parts of the Pacific and Indian oceans, in which atolls or circular coral islands abound, are as gradually sinking. That all the existing continents and submarine abysses may have originated in movements of this kind, continued throughout incalculable periods of time, is undeniable, for marine remains are found in rocks at almost all elevations above the sea, and the denudation which the dry land appears to have suffered, favours the idea that it was raised from the deep by movements of the earth's crust, prolonged throughout indefinite periods. Rain and rivers, aided sometimes by slow and sometimes by sudden and violent movements, have undoubtedly excavated some of the principal valleys; but there are also wide spaces which have been denuded in such a manner as can only be explained by reference to the action of waves and currents on land slowly emerging from the deep.

* See Student's Elements, p. 70.

It may perhaps be said that there is no analogy between the slow upheaval of broad plains or table lands, and the manner in which we must presume all mountain-chains, with their inclined strata, to have originated. It seems, however, that the Andes have been rising century after century, at the rate of several feet, while the Pampas on the east have been raised only a few inches in the same time. Crossing from the Atlantic to the Pacific, in a line passing through Mendoza, Mr. Darwin traversed a plain 800 miles broad, the eastern part of which has emerged from beneath the sea at a very modern period. The slope from the Atlantic is at first very gentle, then greater, until the traveller finds, on reaching Mendoza, that he has gained, almost insensibly, a height of 4,000 feet. The mountainous district then begins suddenly, and its breadth from Mendoza to the shores of the Pacific is 120 miles, the average height of the principal chain being from 15,000 to 16,000 feet, without including some prominent peaks which ascend much higher. Now all we require, to explain the origin of the principal inequalities of level here described, is to imagine, first a zone of more violent movement to the west of Mendoza, and, secondly, to the east of that place, an upheaving force, which died away gradually as it approached the Atlantic. In short, we are only called upon to conceive, that the region of the Andes was pushed up four feet in the same period in which the Pampas near Mendoza rose one foot, and the plains near the shores of the Atlantic one inch. In Europe the land at the North Cape is said to ascend about five feet in a century; farther to the south, as at Gefle, it amounts to two or three feet in the same period, while at Stockholm it does not exceed three or four inches, and at certain points still farther south there is no movement.

But in what manner, it is asked, can we account for the great lateral pressure which has been exerted, not only in the Andes, Alps, and other chains, but also on the strata of many low and nearly level countries? Do not the folding and fracture of the beds, the anticlinal and synclinal ridges and troughs, as they are called, and the vertical, and even sometimes the inverted position of the beds, imply an abruptness

and intensity in the disturbing force wholly different in kind and energy to that which now rends the rocks during ordinary earthquakes? I shall treat more fully in the second volume of the probable subterranean sources, whether of upward or downward movement, and of great lateral pressure, but it may be well briefly to state in this place that in our own times, as, for example, in Chili, in 1822, the volcanic force has overcome the resistance, and permanently uplifted a country of such vast extent that the weight and volume of the Andes must be insignificant in comparison, even if we indulge the most moderate conjectures as to the thickness of the earth's crust above the volcanic foci.

To assume that any set of strata with which we are acquainted are made up of such cohesive and unyielding materials as to be able to resist a power of such stupendous energy, if its direction, instead of being vertical, happened to be oblique or horizontal, would be extremely rash. But if they could yield to a sideway thrust, even in a slight degree, they would become squeezed and folded to any amount if subjected for a sufficient number of times to the repeated action of the same force. We can scarcely doubt that a mass of rock several miles thick was uplifted in Chili in 1822 and 1835, and that a much greater volume of solid matter is upheaved wherever the rise of land is very gradual, as in Scandinavia, the development of heat being probably, in that region, at a greater distance from the surface. If continents, rocked, shaken and fissured, like the western region of South America, or very gently elevated, like Norway and Sweden, do not acquire in a few days or hours an additional height of several thousand feet, this can arise from no lack of mechanical force in the subterranean moving cause. It must arise simply from the antagonist forces having previously become nearly or quite balanced, those of expansion and resistance having approached an equilibrium. The incumbent crust of the earth is never allowed to attain that strength and coherence which would be necessary in order to enable the volcanic force to accumulate and form an explosive charge capable of producing a grand paroxysmal eruption. The subterranean power, on the contrary, displays

even in its most energetic efforts an intermittent and mitigated intensity, being never permitted to lay a whole continent in ruins. Hence the numerous eruptions of lava from the same vent, or chain of vents, and the recurrence of similar earthquakes for thousands of years along certain areas or zones of country. Hence the numerous monuments of the successive ejection and injection of melted matter in ancient geological epochs, and the fissures formed in distinct ages, and often widened and filled at different eras.

Among the causes of lateral pressure, the expansion by heat of large masses of solid stone intervening between others which have a different degree of expansibility, or which happen not to have their temperature raised at the same time, may play an important part. It may also happen that hot vapours or thermal waters charged with various mineral matters in solution, may permeate rocks and augment their volume, while giving rise to new chemical combinations and a metamorphic structure. We shall presently see, when treating of the great thickness of shallow-water deposits of different geological periods, how repeatedly some areas have sunk down hundreds or thousands of feet below their original level, and we can hardly doubt that much of the bending of pliant strata, and the packing of the same into smaller spaces, has taken place during such subsidence. Whether the failure of support be produced by the melting of porous rocks, which, when fluid, and subjected to great pressure, may occupy less room than before, or which, by passing from a pasty to a crystalline condition, may, as in the case of granite, suffer contraction, or whether the sinking be due to the subtraction of lava driven elsewhere to some volcanic orifice, and there forced outwards, or whether it be brought on by the shrinking of solid and stony masses during refrigeration, or by the condensation of gases, or any other imaginable cause, we have no reason to incline to the idea that the consequent geological changes are brought about so suddenly, as that large parts of continents are swallowed up at once in unfathomable subterranean abysses. If cavities be formed, they will be enlarged gradually, and as gradually filled. We read, indeed, accounts of engulphed

cities and areas of limited extent which have sunk down many yards at once; but we have as yet no authentic records of the sudden disappearance of mountains, or the submergence or emergence of great islands. On the other hand, the creeps in coal mines * demonstrate that gravitation begins to act as soon as a moderate quantity of matter is removed even at a great depth. The roof sinks in, or the floor of the mine rises, and the bent strata often assume as regularly a curved and crumpled arrangement as that observed on a grander scale in mountain-chains. The absence, indeed, of chaotic disorder, and the regularity of the plications in geological formations of high antiquity, although not unfrequently adduced to prove the unity and instantaneousness of the disturbing force, might with far greater propriety be brought forward as an argument in favour of the successive application of some irresistible but moderated force.

In conclusion, I may observe that the real point on which the whole controversy turns is the relative amount of work done by mechanical force in given quantities of time, past and present. Before we can determine the relative intensity of the force employed, we must have some fixed standard by which to measure the time expended in its development at two distinct periods. It is not the magnitude of the effects, however gigantic their proportions, which can inform us in the slightest degree whether the operation was sudden or gradual, insensible or paroxysmal. It must be shown that a slow process could never in any series of ages give rise to the same results.

The advocate of paroxysmal energy might assume an uniform and fixed rate of variation in times past and present for the animate world, that is to say, for the dying-out and coming-in of species, and then endeavour to prove that the changes of the inanimate world have not gone on in a corresponding ratio. But the adoption of such a standard of comparison would lead, I suspect, to a theory by no means favourable to the pristine intensity of natural causes. That the present state of the organic world is not stationary, can

* See Lyell's Elements of Geology, p. 50; and Student's Elements, p. 56.

be fairly inferred from the fact, that some species are known to have become extinct in the course even of the last three centuries, and that the exterminating causes always in activity, both on land and in the waters, are very numerous. But granting that a secular variation in the zoological and botanical worlds is going on, and is by no means wholly inappreciable to the naturalist, still it is certainly far less manifest than the revolution always in progress in the inorganic world. Indeed the quantity of sediment annually carried down by several of the most important rivers from the land to the sea, has already been so far measured as to enable the physicist by a simple arithmetical calculation to show approximately in how many years the minimum of change brought about by such a process would be capable of excavating the deepest valleys, and altering the height and volume of continental masses. Or, if we turn to the igneous forces, we find that every year some volcanic eruptions take place, and a rude estimate might be made of the number of cubic feet of lava and scoriæ poured or cast out of various craters. The amount of mud and sand deposited in deltas, and the advance of new land upon the sea, or the annual retreat of wasting sea-cliffs, are changes the amount of which might be roughly estimated. The extent of land raised above or depressed below the level of the sea might also be computed, and the change arising from such movements in a century might be conjectured. Suppose the average rise of the land in some parts of Scandinavia to be as much as two and a half feet in a hundred years, the present sea-coast might be uplifted 350 feet in fourteen thousand years; but we should have no reason to anticipate, from any zoological data hitherto acquired, that the molluscous fauna of the northern seas would in that lapse of years undergo any sensible amount of variation. We discover sea-beaches in Norway 700 feet high, in which the shells are identical with those now living, although their geographical distribution has somewhat altered, the fossil species constituting an assemblage which at present characterises the sea several degrees farther north. The rise of land in Scandinavia, however insensible to the inhabitants, has evidently been rapid when compared to the

rate of contemporaneous change in the testaceous fauna of the German Ocean. Were we to wait, therefore, till the mollusca shall have undergone as much alteration as they underwent between any two of the twelve larger groups from the Laurentian to the Pliocene (enumerated in the table at the end of this chapter), or even in the time intervening between the minor subdivisions of some of these groups, what stupendous revolutions in physical geography ought we not to expect, and how many mountain-chains might not be produced by the repetition of shocks of moderate violence, or by movements not even perceptible to man!

If we turn from the mollusca to the vegetable kingdom, and ask the botanist how many earthquakes and volcanic eruptions might be expected, and how much the relative level of land and sea might be altered, or how far the principal deltas will encroach upon the ocean, or the sea-cliffs recede from the present shores, before the species of European forest-trees will die out, he would reply that such alterations in the inanimate world might be multiplied indefinitely before he should have reason to anticipate, by reference to any known data, that the existing species of trees in our forests would disappear and give place to others. In a word, the movement of the inorganic world is obvious and palpable, and might be likened to the minute-hand of a clock, the progress of which can be seen and heard, whereas the fluctuations of the living creation are nearly invisible, and resemble the motion of the hour-hand of a timepiece. It is only by watching it attentively for some time, and comparing its relative position after an interval, that we can prove the reality of its motion.*

* See the Author's Anniversary Address, Quart. Journ. Geol. Soc. 1850, vol. vi. p. 46, from which some of the above passages are extracted.

Abridged General Table of Fossiliferous Strata; showing their chronological succession and order of superposition.*

1. RECENT.		**POST-TERTIARY.**		NEOZOIC.
2. POST-PLIOCENE.				
3. NEWER PLIOCENE.		**PLIOCENE.**	TERTIARY or CAINOZOIC.	
4. OLDER PLIOCENE.				
5. UPPER MIOCENE.		**MIOCENE.**		
6. LOWER MIOCENE.				
7. UPPER EOCENE.		**EOCENE.**		
8. MIDDLE EOCENE.				
9. LOWER EOCENE.				
10. MAESTRICHT BEDS.		**CRETACEOUS.**	SECONDARY or MESOZOIC.	
11. WHITE CHALK.				
12. CHLORITIC SERIES.				
13. GAULT.				
14. NEOCOMIAN.				
15. WEALDEN.				
16. PURBECK BEDS.		**JURASSIC.**		
17. PORTLAND STONE.				
18. KIMMERIDGE CLAY.				
19. CORAL RAG.				
20. OXFORD CLAY.				
21. GREAT or BATH OOLITE.				
22. INFERIOR OOLITE.				
23. LIAS.				
24. UPPER TRIAS.		**TRIASSIC.**		
25. MIDDLE TRIAS.				
26. LOWER TRIAS.				
27. PERMIAN.		**PERMIAN.**	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
28. COAL-MEASURES.		**CARBONIFEROUS.**		
29. CARBONIFEROUS LIMESTONE.				
30. UPPER	DEVONIAN.	**DEVONIAN.**		
31. MIDDLE				
32. LOWER				
33. UPPER	SILURIAN.	**SILURIAN.**		
34. LOWER				
35. UPPER	CAMBRIAN.	**CAMBRIAN.**		
36. LOWER				
37. UPPER	LAURENTIAN.	**LAURENTIAN.**		
38. LOWER				

* For a more detailed and extended list see Elements of Geology, 6th edit. p. 102; and Student's Elements, p. 109.

CHAPTER VIII.

DIFFERENCE IN TEXTURE OF THE OLDER AND NEWER ROCKS.

CONSOLIDATION OF FOSSILIFEROUS STRATA—SOME DEPOSITS ORIGINALLY SOLID —TRANSITION AND SLATY TEXTURE—CRYSTALLINE CHARACTER OF PLUTONIC AND METAMORPHIC ROCKS—THEORY OF THEIR ORIGIN—ESSENTIALLY SUBTERRANEAN—NO PROOFS THAT THEY WERE PRODUCED MORE ABUNDANTLY AT REMOTE PERIODS.

Consolidation of strata.—Another argument in favour of the dissimilarity of the causes operating at remote and recent eras has been derived by many geologists from the more compact, stony, and crystalline texture of the older as compared to the newer rocks.

This subject may be considered, first, in reference to the fossiliferous strata; and, secondly, in reference to those crystalline and stratified rocks which contain no organic remains, such as gneiss and mica-schist. There can be no doubt that the former of these classes, or the fossiliferous, are generally more compact and stony in proportion as they are more ancient. It is also certain that a great part of them were originally in a soft and incoherent state, and that they have been since consolidated. Thus we find occasionally that shingle and sand have been agglutinated firmly together by a ferruginous or siliceous cement, or that carbonate of lime in solution has been introduced, so as to bind together materials previously incoherent. Organic remains have sometimes suffered a singular transformation, as, for example, where shells, corals and wood are silicified, their calcareous or ligneous matter having been replaced by nearly pure silica. The constituents of some beds have probably set and become hard for the first time when they emerged from beneath the water.

But, on the other hand, we observe in certain formations now in progress, particularly in coral reefs, and in deposits from the waters of mineral springs, both calcareous and siliceous, that the texture of rocks may be stony from the first. This circumstance may account for exceptions to the general rule, not unfrequently met with, where solid strata are superimposed on others of a plastic and incoherent nature, as in the neighbourhood of Paris, where the tertiary formations, consisting often of compact limestone and siliceous grit, are more stony than underlying beds of the same series.

It will readily be understood, that the various solidifying causes, including those above enumerated, together with the pressure of incumbent rocks and the influence of subterranean heat, must all of them require time in order to exert their full power. If in the course of ages they modify the aspect and internal structure of stratified deposits, they will give rise to a general distinctness of character in the older as contrasted with the newer formations.

Transition texture.—In the original classification of Werner, the highly crystalline rocks, such as granite and gneiss, which contain no organic remains, were called primary, and the fossiliferous strata secondary, while to another class of an age intermediate between the primary and secondary he gave the name of transition. They were termed transition because they partook in some degree in their mineral composition of the nature of the most crystalline rocks, such as gneiss and mica-schist, while they resembled the fossiliferous series in containing occasionally organic remains, and also in exhibiting evident signs of a mechanical origin. It was at first imagined, that the rocks having this intermediate texture had been all deposited subsequently to the series called primary, and before all the more earthy and fossiliferous formations. But when the relative position and organic remains of these transition rocks were better understood, it was perceived that they did not all belong to one period. On the contrary, the same mineral characters were found in strata of very different ages, and some formations occurring

in the Alps, which several of the ablest scholars of Werner had determined to be transition, were ultimately ascertained, by means of their fossil contents and position, to be members of the Cretaceous, and even of the nummulitic or older Tertiary period. These strata had, in fact, acquired the *transition* texture from the influence of causes which, since their deposition, had modified their internal arrangement.

Texture and origin of Plutonic and metamorphic rocks.—Among the most singular of the changes superinduced on rocks, we have occasionally to include the slaty texture, the divisional planes of which sometimes intersect the true planes of stratification, and even pass directly through imbedded fossils. If, then, the crystalline, the slaty, and other modes of arrangement, once deemed characteristic of certain periods in the history of the earth, have in reality been assumed by fossiliferous rocks of different ages and at different times, we are prepared to enquire whether the same may not be true of the most highly crystalline state, such as that of gneiss, mica-schist, and statuary marble. That the peculiar characteristics of such rocks are really due to a variety of modifying causes is now very generally admitted, and the differences of opinion among geologists which still prevail, relate chiefly to the manner in which the transformation has been brought about. According to the original Neptunian theory, all the crystalline formations were precipitated from a universal menstruum or chaotic fluid antecedently to the creation of animals and plants, the unstratified granite having been first thrown down so as to serve as a floor or foundation on which gneiss and other stratified rocks might repose. Afterwards, when the igneous origin of granite was no longer disputed, many conceived that a thermal ocean enveloped the globe, at a time when the first-formed crust of granite was cooling, but when it still retained much of its heat. The hot waters of this ocean held in solution the ingredients of gneiss, mica-schist, hornblende-schist, clay-slate, and marble, rocks which were precipitated, one after the other, in a crystalline form. No fossils could be enclosed in them, the high temperature of the fluid, and the quantity of mineral matter which

it held in solution, rendering it unfit for the support of organic beings.

It would be inconsistent with the plan of this work to enter here into a detailed account of what I have elsewhere termed the *metamorphic theory*;* but I may state that it is now demonstrable in some countries that fossiliferous formations, some of them older than the Cambrian strata of our table, p. 135, others of the age of the Silurian strata, as near Christiana in Norway, others belonging to the Oolitic period, as around Carrara in Italy, and some even of tertiary date, as in the Swiss Alps, have been converted into gneiss, mica-schist, or statuary marble. The transmutation has been effected by the influence of subterranean heat acting under great pressure, and aided by thermal water or steam and other gases permeating the porous rocks, and giving rise to various chemical decompositions and new combinations, the whole of which action has been termed 'plutonic,' as expressing in one word all the modifying causes brought into play at great depths, and under conditions never exemplified at the surface.† To this Plutonic action the fusion of granite itself in the bowels of the earth, as well as the development of the metamorphic texture in sedimentary strata, may be attributed; and in accordance with these views the age of each metamorphic formation may be said to be twofold, for we have first to consider the period when it originated, as an aqueous deposit, in the form of mud, sand, marl, or limestone; secondly, the date at which it acquired a crystalline texture. The same strata, therefore, may, according to this view, be very ancient in reference to the time of their deposition, and comparatively modern in regard to the period of their assuming the metamorphic character.

No proofs that these crystalline rocks were produced more abundantly at remote periods.—Several modern writers, without denying the truth of the Plutonic or metamorphic theory, still contend that the crystalline and non-fossiliferous formations, whether stratified or unstratified, such as gneiss and

* See Lyell's Elements, ch. xxxv.; and Student's Elements, p. 560.

† See Student's Elements: Remarks on hydrothermal action, p. 568.

granite, are essentially ancient as a class of rocks. They were generated, say they, most abundantly in a primeval state of the globe, since which time the quantity produced has been always on the decrease, until it became very inconsiderable in the Oolitic and Cretaceous periods, and quite evanescent before the commencement of the tertiary epoch.

Now the justness of these views depends almost entirely on the question whether granite, gneiss, and other rocks of the same order ever originated as such at the surface, or whether, according to the opinions above adopted, they are essentially subterranean in their origin, and therefore entitled to the appellation of *hypogene*. If they were formed superficially in their present state, and as copiously in the modern as in the more ancient periods, we ought to see a greater abundance of tertiary and secondary than of primary granite and gneiss; but if we adopt the theory of their subterranean origin, their rapid diminution in volume among the visible rocks in the earth's crust in proportion as we investigate the formations of newer date, is quite intelligible. If a melted mass of matter be now cooling very slowly at the depth of several miles beneath the crater of an active volcano, it must remain invisible until great revolutions in the earth's crust have been brought about. So also if stratified rocks are now by hydrothermal action, or under the influence of intensely heated steam and other gases, undergoing semi-fusion and reconstruction far underground, it will probably require the lapse of many periods before they will be forced up to the surface and exposed to view by denudation, even at a single point. To effect this purpose there may be need of as great a development of subterranean movement as that which in the Alps, Andes, and Himalayas has raised strata containing marine fossil shells and ammonites to the height of 8,000, 14,000, and 16,000 feet. By parity of reasoning we can hardly expect that any tertiary rocks of the hypogene class will have been brought within the reach of human observation, save at a few isolated points, seeing that the emergence of such rocks must always be so long posterior to the date of their origin; and,

as extensive denudation must also combine with upheaval before they can be displayed at the surface throughout wide areas, formations of this class cannot become generally visible until so much time has elapsed as to confer on them a high relative antiquity.

All geologists who reflect on subterranean movements now going on, and the eruptions of active volcanos, are convinced that great changes are now continually in progress in the interior of the earth's crust far out of sight. They must be conscious, therefore, that the inaccessibility of the regions in which these alterations are taking place compels them to remain in ignorance of a great part of the working of existing causes, so that they can only form vague conjectures in regard to the nature of the products which volcanic heat, aided by steam and various gases, may elaborate under great pressure.

When therefore they find in mountain-chains of high antiquity, that what was once the interior of the earth's crust has since been forced outwards by mechanical violence or exposed to view by denudation, they may expect to behold some of the nether formed rocks of remote eras, the modern representatives of which they cannot see. They may be prepared to find that these rocks will differ wholly from the fossiliferous strata deposited at the surface and from the lava and scoriæ thrown out by modern volcanos in the open air. They may recognise in granite, gneiss, mica-schist, hornblende schist, and other crystalline rocks, products of a nature and aspect distinct from those which they have observed in process of formation, and these they may therefore be ready to refer to the action of subterranean heat and gases under great pressure.

The contrast in the characters, both positive and negative, of such rocks with those which are known to be of superficial origin is a reason for referring them to operations which the geologist has had no opportunities of observing. The anomalous appearances are the result, not of an order of things which has passed away, but of a set of conditions removed by their very nature from the possibility of being

observed. They are not the monuments of the primeval period, bearing inscribed upon them in obsolete characters the words and phrases of a dead language; but they teach us that part of the living language of nature which we cannot learn by our daily intercourse with what passes on the habitable surface.

CHAPTER IX.

THEORY OF THE PROGRESSIVE DEVELOPMENT OF ORGANIC LIFE AT SUCCESSIVE GEOLOGICAL PERIODS.

THEORY OF THE PROGRESSIVE DEVELOPMENT OF ORGANIC LIFE—EVIDENCE IN ITS SUPPORT DERIVED FROM FOSSIL PLANTS—FOSSIL ANIMALS—MOLLUSCA—WHETHER THEY HAVE ADVANCED IN GRADE SINCE THE EARLIEST ROCKS WERE FORMED—HIGH ANTIQUITY OF CEPHALOPODA—SLIGHT INDICATIONS OF PROGRESS AFFORDED BY FOSSIL FISH—FOSSIL AMPHIBIA—TRUE REPTILES—TRANSITIONAL LINK BETWEEN REPTILES AND BIRDS—LAND ANIMALS OF REMOTE PERIODS WHY RARE—FOSSIL BIRDS—MAMMALIA—STONESFIELD MARSUPIALS—ABSENCE OF CETACEA IN SECONDARY ROCKS—SUCCESSIVE APPEARANCE OF THE GREAT SUB-CLASSES OF MAMMALIA OF ADVANCING GRADE IN CHRONOLOGICAL ORDER—MODERN ORIGIN OF MAN—INTRODUCTION OF MAN, TO WHAT EXTENT CHANGE IN THE SYSTEM.

In the last three chapters we considered whether the doctrine of the greater intensity of the aqueous and igneous forces in remote ages has any foundation in fact, and whether the peculiar crystalline texture of many of the older rocks favours the opinion that the former changes in the earth's crust, of which geology treats, were brought about by other than ordinary causes. We may now discuss the arguments derived from the organic creation in support of the notion that there is a want of analogy and continuity between the past and present course of events in the natural world. The objections on this head were formally stated in 1830, by the late Sir Humphry Davy. 'It is impossible,' he affirms, 'to defend the proposition, that the present order of things is the ancient and constant order of nature, only modified by existing laws: in those strata which are deepest, and which must, consequently, be supposed to be the earliest deposited, forms even of vegetable life are rare; shells and vegetable remains are found in the next order; the bones of fishes and oviparous reptiles exist in the following class; the remains

of birds, with those of the same genera mentioned before, in the next order; those of quadrupeds of extinct species in a still more recent class; and it is only in the loose and slightly consolidated strata of gravel and sand, and which are usually called diluvial formations, that the remains of animals such as now people the globe are found, with others belonging to extinct species. But, in none of these formations, whether called secondary, tertiary, or diluvial, have the remains of man, or any of his works, been discovered; and whoever dwells upon this subject must be convinced, that the present order of things, and the comparatively recent existence of man as the master of the globe, is as certain as the destruction of a former and a different order, and the extinction of a number of living forms which have no types in being. In the oldest secondary strata there are no remains of such animals as now belong to the surface; and in the rocks, which may be regarded as more recently deposited, these remains occur but rarely, and with abundance of extinct species;—there seems, as it were, a gradual approach to the present system of things, and a succession of destructions and creations preparatory to the existence of man.*

In the above passages the author has done little more than reiterate the theory of progression which Lamarck had proposed about thirty years before in his Philosophy of Zoology. Another interval of more than forty years has again elapsed since Davy wrote, one marked by ever-increasing activity in palæontological research, yet the new facts brought to light have scarcely overturned any of the leading propositions above enumerated, although several of them have required to be considerably modified. Fossil remains of man and rude works of art have, it is true, been detected in the formations termed by Sir H. Davy diluvial, in which the bones of the mammoth and other extinct quadrupeds so frequently occur. But, although these discoveries have enabled us to trace back the memorials of our race one short step farther into the past, they have not shaken our belief in the extremely modern date of the human era, as compared to that of a

* Sir H. Davy, Consolations in Travel: Dialogue III. 'The Unknown.'

series of antecedent epochs, each of them characterised by distinct species of animals and plants.* The dates of the successive appearance of certain classes, orders, and genera, those of higher organisation always characterising rocks newer in the series, have often been mis-stated,† and the detection of chronological errors has engendered doubts as to the soundness of the theory of progression. In these doubts I myself indulged freely in former editions of this work. But after numerous corrections have been made as to the date of the earliest signs of life on the globe, and the periods when more highly organised beings, whether animal or vegetable, first entered on the stage, the original theory may be defended in a form but slightly modified.

Fossil Plants.—To speak first of the vegetable creation—recent investigations have made it more and more clear that the oldest known flora was characterised by a great predominance of cryptogamous plants. In the Devonian flora of North America the lycopodiaceous genera, such as the Lepidodendra, were the most numerous, while the associated plants, such as Sigillariæ, ferns, and Coniferæ, although they are specifically distinct, agree generically with those of the carboniferous strata which come next in succession. It had been suggested that the absence, in the true coal, of the higher grade of flowering plants, (the dicotyledonous angiosperms of Brongniart,) which now constitute three-fourths of the vegetation of the globe, might be explained by supposing that the fossil species represent those only which grew in a particular class of stations, such as low swamps bordering the sea; and that more highly organised genera and species would have become known to us, had we been acquainted with the flora of the higher and mountainous regions. But although it is now universally admitted that the plants which form the bulk of the coal grew on the spots where we now find that fuel, yet there are many vegetable remains in the

* In my work on the Antiquity of Man, 1863, I have given, p. 295, a concise statement of the doctrine of progression as laid down by Prof. Sedgwick, the late Hugh Miller, M. Agassiz, Prof. Owen, and Profs. Bronn and Adolphe Brongniart, as applied both to the animal and vegetable worlds, which I need not repeat in the present chapter.

† See my Elements of Geology, p. 853.

associated sandstones, which must have been drifted from a distance or washed down by great rivers from higher grounds to the sea-coast. Nor can we point to a marsh in the delta of any existing river, where ferns and other Cryptogams together with Coniferæ flourish, to the exclusion of all the more highly organised plants.

Certain fruits and leaves of the coal-measures, formerly supposed to be those of palms, are now very generally referred to plants of less perfect structure, being variously classed by botanists as cycads, conifers, or lycopodiaceæ. There seems also ground for suspecting, in accordance with the suggestion of Dr. Dawson, that the flora of the Devonian rocks of North America was of a more upland character than that of the coal, and the mere fact of our having traced this ancient vegetation (the Devonian and Carboniferous), consisting of several hundred species, over so vast an area in space, in Europe and North America, and through such a lapse of ages, makes it probable that we have already obtained a correct notion of the leading features of the botany, both upland and lowland, of those palæozoic times. The almost entire want in this fossil flora, the first which geology has yet revealed to us, of plants of the most complex organisation is very striking, for not a single dicotyledonous angiosperm has yet been proved to exist in any primary formation, and only one undoubted monocotyledon,* although these two great divisions taken together form four-fifths of our living vegetation.

In regard to secondary or mesozoic times, all botanists agree that palms, with some other monocotyledons, were already in existence; but it seems doubtful whether any trace of a dicotyledonous angiosperm has yet been detected in rocks of the Triassic, Oolitic, or Lower Cretaceous (Neocomian), periods. Conifers, cycads, and ferns abounded, but the plants which now constitute the larger portion of our flora, and comprise all the native European trees except those of the fir tribe, seem not to have come into being, and must certainly have been extremely rare before the Upper Cretaceous

* *Pothocites Grantonii*, Paterson, from the coal shale of Granton near Edinburgh. Edin. Bot. Soc. Trans. vol. i. plate 3. 1844. This plant, which is referred to the family Aroideæ, has the spike well preserved.

era. It is in strata of this latter age, at Aix-la-Chapelle, that we at length meet with an assemblage of fossil plants, in which the principal classes and orders of the living vegetable creation are fully represented. The variety and completeness of the fossil flora then attained continued to be conspicuous throughout a long succession of tertiary ages, in which the forms were perpetually changing, but always becoming more and more like, generically and specifically, to those now in being. On the whole there appears therefore to have been an advance in the fossil flora in the course of ages, although the cryptogamous plants of the Primary periods were some of them more perfect or of a higher grade than any of the same class now living. The Gymnogens (cycads and conifers) became more abundant, as also the Monocotyledons in the Secondary epochs, while in the Tertiary periods all the leading forms of the most complex dicotyledons now inhabiting the globe appear to have flourished.

Fossil Animals.—We may next turn to the animal kingdom, and consider the arguments derived from fossil vertebrata and invertebrata in favour of progressive development. Whenever these arguments are founded on negative evidence, we cannot be too cautious in our reasoning, and we must always bear in mind that it has been evidently no part of the plan of Nature to hand down to us a complete or systematic record of the former history of the animate world. We may have failed to discover a single shell, marine or fresh-water, or a single coral or bone in shale or sandstone, even in such a formation as that of the valley of the Connecticut, in which the footprints of bipeds and quadrupeds abound; but such failure may have arisen, not because the population of the land or sea was scanty at that era, but because in general the preservation of any relics of the animals or plants of former times in sedimentary formations is the exception to a general rule. It is only when the rocks are made up bodily of the remains of plants or animals, as in the case of beds of coal, chalk, or coral-limestone, that a representation of certain classes of the animal kingdom can be looked for as constituting an essential part of the formation. Time so enormous as that contemplated by the geologist may multiply exceptional cases till they seem to

constitute the rule, and so impose on the imagination as to lead us to infer the non-existence of creatures of which no monuments happen to remain. The late Edward Forbes remarked, that few geologists are aware how large a proportion of all known species of fossils are founded on single specimens, while a still greater number are founded on a few individuals discovered in one spot. This holds true not only in regard to animals and plants inhabiting the land, the lake, and the river, but even to a surprising number of the marine mollusca, articulata, and radiata. Our knowledge, therefore, of the living creation of any given period of the past may be said to depend in a great degree on what we commonly call chance, and the casual discovery of some new localities rich in peculiar fossils may modify, and, to a great extent, overthrow all our previous generalisations.

Mollusca.—Of all the invertebrate animals, the mollusca are the most important in geology, as, owing to the durable nature of their shells, they have been more generally preserved, in strata of every age, than the memorials of any other creatures. They are also peculiarly well fitted to throw light on the controverted question whether there has or has not been a gradual advance in the course of ages, from the humbler and more simple to the higher and more complex grades of structure. By a higher or more perfect organisation is meant one in which there are a greater number of organs specially devoted to particular functions. Thus in the lowest divisions, such as the Bryozoa and Brachiopoda, we find no separate organs of respiration, sight, or locomotion; whereas, in the lamellibranchiate bivalves, although they are without heads, we find a heart, mouth, gills, and foot, with several other organs, wanting in the inferior orders before alluded to. The Gasteropoda, again, have a head, mouth, lingual teeth, a special breathing apparatus, and nearly all of them organs of sight, while in the highest grade, the Cephalopoda, we meet with so many instruments appointed to perform distinct functions, such a concentration of the nervous system in what may be regarded as a brain, such acuteness of the senses, especially those of sight and touch, with such powers of locomotion, that we cannot refuse to assign to them a place supe-

rior to that of all the other mollusca, and even to some few species of the vertebrata, although these last belong to a type which as a whole ranks so much higher in the scale.

We have now, therefore, to enquire whether the fossil representatives of the different divisions of the mollusca above enumerated, the Bryozoa, Brachiopoda, Lamellibranchiata, Gasteropoda, and Cephalopoda, made their appearance in succession in the ancient seas in the same order of time as they would stand in an ascending series in a zoological classification. In our endeavour to reply to this question it will be well to exclude from our survey the fossils of the lowest strata, or those older than the Lower Silurian (Nos. 35 and 36 of the Table, p. 135), with which we are so imperfectly acquainted that it is dangerous to derive from them any conclusions founded simply on negative evidence. Additions made from year to year may change the whole aspect of this primordial fauna of Barrande. Already indeed the notion of the extreme scarcity of organic remains and their inferiority of grade has to some extent had to be abandoned by the detection in it of an Orthoceras and of a rich fauna of trilobites, as well as other forms of life.

To begin then with the Lower Silurian (No. 34 of the same table), we find that it contains representatives of all the groups to which we have alluded, and the Cephalopoda alone have already furnished the conchologist with several hundred species and a long list of genera. Many of these chambered shells, especially the Orthocerata, were of large size, and they may possibly have swarmed the more in the ancient ocean because there were no fishes to compete with them. It has been remarked by the advocates of 'progressive evolution,' that all the cephalopods of this era are referable to the tetrabranchiata, or four-gilled form, a family which is not so highly organised as the dibranchiata (or two-gilled), to which the belemnites, so abundant in the Lias, Oolite, and Chalk, as well as the living cuttlefish, belong. Doubtless the absence of all genera of this highest order from the Silurian, Devonian, and Carboniferous formations may seem to imply that the testaceous fauna of the older rocks had not yet obtained so high a grade as it afterwards reached. But the

cogency of such reasoning is somewhat weakened by the fact, that several genera of Octopods now exist in our seas, which are without internal bones, like those possessed by the Sepia, or external shells, like those of the Nautilus. Such soft-bodied cephalopods, therefore, could not be expected to leave behind them any lasting memorials of their existence. It is only by assuming that there were no such genera in the palæozoic seas, that we can confidently infer a comparative inferiority of grade for the mollusca of that early period. It has been also remarked, in reference to the testaceous fauna of the primary strata, that while the lamellibranchiate bivalves are comparatively few in number, brachiopods of every variety of form are exceedingly abundant. It cannot be denied that the profusion of these last fixes on this earlier fauna a stamp of inferiority. But if we lay much stress on this argument, we find that it is somewhat counterbalanced by evidence bearing in an opposite direction, and equally derived from the proportional number of the representatives of different orders of mollusca. If the Brachiopoda outnumber the Lamellibranchiata in species, so, on the other hand, do the Cephalopods outnumber the Gasteropods, especially the highest division of these last, those which are siphonated, and which as zoophagous, marine animals seem to have been superseded by the Orthocerata, Nautilus, and their congeners. In this case, these last, being mollusca of a higher grade, discharged functions now performed to a great extent by Gasteropods, which are lower in the scale. On the whole, it cannot be said that the successive development, in the course of past ages, of higher and more complex structures, is by any means conspicuous in that grand branch of the animal kingdom which is most largely represented in a fossil state. The variety perhaps of types in the testacea is greater now than at any former period, but the rate of advance in organisation has been slow indeed, if the only step realised between Lower Silurian and modern times can be expressed by the passage from a tetrabranchiate to a dibranchiate cephalopod. According to such a rate of progress, we may well conceive that it might require a course of ages anterior to the Silurian epoch as great as that which has

since elapsed, in order to bring about a gradual evolution from a bryozoon to an orthoceras.

Fossil Fish.—The failure of the palæontologist to detect a single bone of any aquatic animal of the vertebrate class in rocks older than the Ludlow formation of Murchison, one of the uppermost divisions of the Silurian system, is a fact of no small weight in favour of progressive development, although as the oldest fish (Pteraspis), alluded to above, is by no means of the lowest grade, we may still expect to trace back the memorials of the great class of fishes to strata of higher antiquity. But when we consider how rich a molluscous fauna—to say nothing of the crustaceans, sea-urchins, stone-lilies, and corals—has been met with in Silurian rocks in almost all parts of the world, it seems impossible to account for our not having yet found any accompanying bones of fish, except by supposing that they were not yet in being, or that they only occupied a limited area. To verify the date of the first appearance of any new type of organisation is perhaps more than we can reasonably expect, as the first representatives of such types probably originate in one region only, from which they would spread very slowly over the globe.

Next to the Silurian comes the Old Red Sandstone or Devonian formation, which is so rich in fishes that the number of British species alone described by Agassiz, in 1844, amounted to sixty-five, and the number has since been raised to more than a hundred. Almost all of these belonged to the order of Ganoids, and some few only to that of the Placoids, of Agassiz; and it is remarkable that the vast majority of the fossil fish of the succeeding formations, from the Carboniferous to the Oolitic, consist in like manner of Ganoids, a family which, though so rich in genera in the olden times, is of quite exceptional occurrence at the present day, being confined to the North-American rivers, and those of Africa north of the line. In the chalk, and still more in the tertiary formations, we find the majority of the fish to belong to a great variety of genera of the class called *Teleostei* because their skeletons are perfectly ossified, which is very rarely the case with the Ganoids of the older rocks. The cartilaginous, persistent nature of the spinal column or

notochord, which is not divided into separate vertebræ, is regarded on the whole as a mark of a lower grade, as is also the form of the tail called heterocercal, which is almost universal in fish older than the chalk. Nearly all the living fish have equilobed tails, and the heterocercal or inequilobed form is looked upon by Owen as a retention of the embryonic character, or an instance of arrested development. But the affinity of the ancient Placoid and Ganoid fishes in the structure of their heart, brain, generative organs, and many other characters to living sharks, as well as to the African Polypterous and the bony pike, or Lepidosteus, of America, leads the anatomist to assign to them by no means a low place in the piscine class. In short, a retrospect of the history of this class in geological time 'imparts,' according to Professor Owen, 'an idea rather of mutation than of progression.'*

Reptiles.—No well-authenticated example of a reptile occurring in strata so old as the Devonian has yet been established,† and even in the succeeding Carboniferous formation, it was not till the year 1844 that some representatives of the lowest division of this class, the amphibia, which are regarded by some naturalists as intermediate between reptiles and fish, were discovered in the coal of Saarbruck. In 1852 Dr. Dawson and I discovered the osseous remains of a reptile in the Carboniferous strata of Nova Scotia, and in the same formation and country three other genera, all air-breathers, were found by Dr. Dawson, and described by him in his 'Air-breathers of the Coal.' Since that period several genera of the Labyrinthodont family, some containing species of large size, have been found in the carboniferous rocks of North America and Britain. So late as 1865, four or five new genera of this family determined by Professor Huxley have been added from the coal of Tipperary in Ireland. Some of these have well-ossified bony skeletons, although they belong to that sub-class which, like the frogs and newts, possessed gills at some period of their existence, and were also marked by other piscine characters. In rocks

* Owen's Palæontology, 2nd edit. p. 175.

† See Elements of Geology, 6th edition, p. 526 *note*.

of later age, from the Triassic to the Cretaceous inclusive, there is an extraordinary profusion of reptile life, to which I shall have occasion to allude again in the eleventh chapter, when treating of changes in climate. Two orders, the Dinosauria and Compsognatha, have been denominated Ornithoscelida, because, as Professor Huxley has especially pointed out, they supply in some important parts of their structure a transitional link between the reptiles and birds, more especially in the case of the *Compsognathus longipes*, a fossil form of the Solenhofen slate, a member of the Jurassic formation. The hind limbs in particular of these Ornithoscelida are much more similar to those of birds than they are to those of reptiles, and these bird-reptiles, or reptile-birds, were more or less completely bipedal.* No form of reptiles is so remarkable in the Secondary or Mesozoic formation as the winged reptiles called Pterodactyls, which sometimes attain a great size, one of them from the Kentish chalk measuring more than sixteen feet from tip to tip of its outstretched wings, and another in strata of the same age in America attaining even larger dimensions. Their batlike wings were not composed of feathers, as in birds, but appear to have consisted of an extended membrane which was supported, like that of bats, by the fourth digit, which was enormously elongated. They resemble birds in many of their osteological characters, among others in the presence of air-cavities in their bones, the prominent median crest of the broad breast-bone, and often in their horn-sheathed beaks. But they are, says Professor Huxley, rather a sort of reptilian bat than links between reptiles and birds.

Scarcity of Air-breathers in Primary rocks.—Our information respecting the fossils of the oldest rocks, especially those anterior to the Old Red Sandstone or Devonian formation, is almost exclusively derived from strata of marine origin. This we might have anticipated, if the ocean always occupied, as it does now, nearly five parts in seven of the earth's surface. After many geographical revolutions, after the sinking down of ancient continents and the upheaval of newer ones, it is natural that the strata of a very remote age

* Huxley, Pres. Add. Geol. Quart. Journ. 1870, vol. xxvi.

should coincide generally with the bed of the ancient ocean, rather than with the space which was occupied by land. Well therefore may we despair of gaining more than a superficial acquaintance with the terrestrial plants and air-breathing animals which once belonged to those small areas which represent spaces where palæozoic land of Silurian or Cambrian date may have happened to coincide with a portion of our present continents and islands. Even if they had never been submerged from the earliest period, they would have suffered such denudation by rain and rivers, either when the land was stationary, or when it was undergoing changes of level, that no parts of the old surface, or of its lacustrine and fluviatile deposits, would remain. Our best chance of hitting upon the spots where some monuments of such early times have escaped destruction, would arise from their submergence and the accumulation of marine strata upon them or upon the littoral deposits found in the immediate neighbourhood. Even then we could only obtain access to the buried strata, whether fresh-water or littoral, at those points where they had been exposed to view by the partial waste of the incumbent formations. The general absence therefore in Cambrian, Silurian, and Devonian rocks of all remains of land animals is not to be wondered at, and taken alone raises no very strong presumption against the existence, in palæozoic times, of air-breathers of the most highly organised class.

Up to the year 1865 only a few insects had been obtained even from the Carboniferous strata, the land plants of which are well known to us, and none from the Devonian. From this last formation several have now been brought to light in North America, chiefly of the order *Neuroptera*, found by Mr. Hartt, in rocks near St. John~~'s~~, New Brunswick, and determined by Mr. Scudder, of Boston, U.S. Why then should we despair of finding in our future researches some air-breathers of a much higher order than insects, which may have peopled the forests of the Devonian era, in which some flowering plants of the monocotyledonous class, together with pines, tree-ferns, Sigillariæ, and Lepidodendra or gigantic Lycopodiaceæ, flourished. The first pulmoniferous mollusk,

a land shell, called *Pupa Vetusta*, of which hundreds of individuals have now been detected, was not discovered in the coal measures until the year 1852, in Nova Scotia.

Birds.—In regard to birds, they are usually wanting, for reasons to be explained in the next volume, in deposits of all ages, even in the tertiary periods, where we know that birds as well as land quadrupeds abounded. But in the lithographic stone of Solenhofen, a division of the Upper Oolite, a skeleton of a bird almost entire, and retaining even some of its feathers, was found in 1862, and determined by Professor Owen to belong to the class Aves. It differs from all living birds in the structure of its fore limbs and still more of its tail, in which last there were no less than twenty vertebræ, each of them supporting a pair of plumes. In the tail of living birds the coalescence or anchylosed state of the terminal vertebræ is a constant character, the vertebræ being distinct and separate only in the embryo. The tail of the Archeopteryx therefore exhibits, as Professor Owen has pointed out, an earlier or more embryonic type persistent in the full-grown individual. Although no skeletons of the feathered tribe have been found in rocks older than the Oolite, yet the footmarks of a great variety of species of various sizes, some larger than an ostrich, others smaller than the plover, have been observed in rocks of higher antiquity in North America.* These bipeds have left the marks of their footsteps on strata of Triassic age in the valley of the Connecticut, and they are useful in warning us against speculating on the relative grade of ancient and modern representatives of this class, seeing that, although there were so many of these bipeds, we are so ignorant of their structure. Hitherto, even footprints of the class Aves have eluded our search in all formations older than the Trias, so that we may declare at present that the first appearance of fish, reptiles, and birds follows a chronological order in accordance with the position which the same classes would occupy when arranged zoologically by a naturalist in an ascending series: and we shall presently see that the lowest class of Mammalia

* See Hitchcock's Report on Geol. of Massachussets, and Lyell's Travels in North America, chap. 12.

have not yet been traced back so far as the footprints of the earliest known birds.

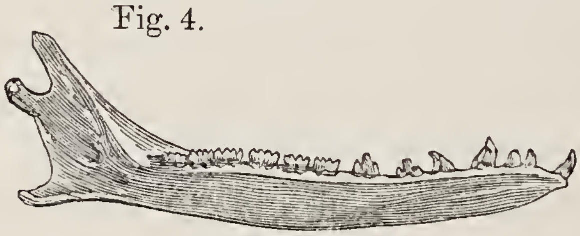
Mammalia.—So late as the beginning of the present century it was a generally received dogma in geology that the

Fig. 3.

Thylacotherium Prevostii (*Valenciennes*). Amphitherium (*Owen*). Lower jaw, from the slate of Stonesfield, near Oxford.*

Mammalia had not been created before the Tertiary period, and the first announcement of the discovery in the Lower Oolite of Stonesfield, of the jaw of a small marsupial, recog-

Fig. 4.



Myrmecobius fasciatus (*Waterhouse*). Recent, from Swan River. Lower jaw of the natural size.†

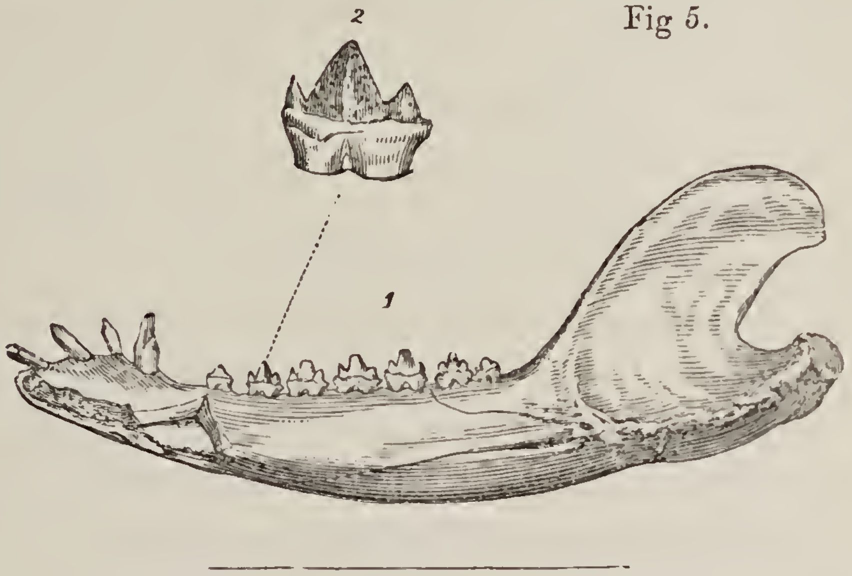
nised as such in 1818 by Cuvier, caused a sensation almost as great as would now be excited by our finding the bones of

* This figure (No. 3) is from a drawing by Professor C. Prevost, published Ann. des Sci. nat. avril 1825. The fossil is a lower jaw, adhering by its inner side to the slab of oolite, in which it is sunk. The form of the condyle, or posterior process of the jaw, is convex, agreeing with the mammiferous type, and is distinctly seen, an impression of it being left on the stone, although in this specimen the bone is wanting. The anterior part of the jaw has been partially broken away, so that the double fangs of the molar teeth are seen fixed in their sockets, the form of the fangs being characteristic of the mammalia. Ten molars are preserved, and the place of an eleventh is believed to be apparent. The enamel of some of the teeth is well preserved.

† A coloured figure of this small and elegant quadruped is given in the Trans. Zool. Soc. vol. ii. pl. 28. It is insectivorous, and was taken in a hollow tree, in a country abounding in ant-hills, ninety miles to the south-east of the mouth of Swan River in Australia. —It is the first living marsupial species known to have nine molar teeth in the lower jaw, and some of the teeth are widely separated from others, one of the peculiarities in the Thylacotherium of Stonesfield, which at first induced M. Blainville to refer that creature to the class of reptiles.

some quadrumanous animal in one of the Secondary rocks. Many naturalists, rather than allow their faith in the theory of progressive development to be so rudely shaken, cherished to the last a hope that it might ultimately turn out that the

Fig 5.



Natural size.

Phascolotherium Bucklandi (*Owen*). (*Syn.* Didelphis Bucklandi, *Brod.*) Lower jaw, from Stonesfield.*

1 The jaw magnified twice in length. 2 The second molar tooth magnified six times.

Fig. 6.

JAW OF STEREOGNATHUS, FROM STONESFIELD.

a. Portion of jaw with three molar teeth from Stonesfield oolite. Natural size. (*Owen's* Palæontology, p. 345.) *b.* Middle tooth of the three contained in the jaw *a.* (*Owen, Ibid.*, p. 346.)

British geologists had been mistaken in their opinion as to the age of the deposit in which this precious relic was entombed : while other eminent anatomists, M. Blainville among the number, called in question the mammalian character of

* This figure (No. 5) was taken from the original, formerly in Mr. Broderip's collection, and now in the British Museum. It consists of the right half of a lower jaw, of which the inner side is seen. The jaw contains seven molar teeth, one canine and three incisors ; but the end of the jaw is fractured, and traces of the alveolus of a fourth incisor are to be seen. With this addition, the number of teeth would agree exactly with those of a didelphis. The fossil is well preserved in a slab of oolitic structure containing shells of trigonia and other marine remains. See Broderip, Zool. Journ. vol. iii. p. 408. Owen, Proceedings Geol. Soc., November 1838.

the relic. But no less than nine other specimens of lower jaws of mammiferous quadrupeds have since been met with in the same slate of Stonesfield, so that, including the first found (fig. 3, p. 156), there are now four distinct species referable to three genera in this one member of the Lower Oolite.

After Cuvier had referred the specimen first met with to a marsupial, Professor Owen pointed out that the extinct genus to which it belonged had considerable affinity to an Australian mammifer, the *Myrmecobius* of Waterhouse, which has nine molar teeth in the lower jaw (see fig. 4).

The next representative of the same class found in the same slate was at once regarded as an opossum, with which it agrees nearly in osteological character, and precisely in the number of its teeth (fig. 5, p. 157). But the most remarkable of all the mammalia of which the remains have been found at Stonesfield, was that made known to the scientific world in 1854, under the name of *Stereognathus*.* The portion found consisted of part of a lower jaw containing three double-fanged teeth, indicating an animal small in size, but larger than any of the other quadrupeds as yet obtained from those rocks (see fig. 6). Although the teeth differed in structure from those of any recent or fossil animal yet known, they are admitted by anatomists to have more affinity to the higher or placental division of mammalia than any of the species previously found at Stonesfield, or those yet procured from any rocks older than the Tertiary. It is conjectured by Professor Owen that it may have been a small, hoofed, herbivorous animal, or at least a mixed feeder, but he still regards this conclusion as doubtful; so far does *Stereognathus* depart from any known type, whether living or extinct.

When the Stonesfield oolite had continued for nearly thirty years to be the only rock which had in any part of the world afforded an example of a fossil mammifer anterior in date to the Tertiary period, the tooth of another small marsupial mammifer, called Microlestes, was discovered in the Upper

* This generic name was given to it in 1854, by Mr. Charlesworth, who obtained it from the Rev. J. P. Dennis, in whose possession it had been for twenty years or more.

Trias of Stuttgardt in 1847.* Between that year and 1863 this rock and the Upper Trias of Somersetshire have yielded three species of the same genus, and a stratum probably of about the same age in North Carolina has supplied us with three jaws of a small insectivorous mammal, probably marsupial, called by the late Professor Emmons *Dromatherium sylvestre.* The only other mammalia as yet discovered in any other part of the globe in formations older than the Eocene are those of the uppermost Oolite or Purbeck strata in Dorsetshire, where about twenty-five species, referable to about eleven genera, have been met with between the years 1854 and 1871, all very small, most of them decidedly marsupial, and the rest, if not of the same sub-class, belonging to insectivora of low grade.†

It may, no doubt, be said that our acquaintance with the purely fresh-water strata of periods older than the Secondary is very defective, and that we ought therefore to expect that memorials of land animals in marine strata of Primary or Palæozoic date would be very exceptional. There are regions at present, in the Indian and Pacific Oceans, coextensive in area with Europe and North America, where we might dredge the bottom and draw up thousands of shells and corals, without obtaining one bone of a land quadruped. Suppose our mariners were to report that, on sounding in the Indian Ocean near some coral reefs, and at some distance from the land, they drew up on hooks attached to their line portions of an ape, elephant, or leopard, should we not be sceptical as to the accuracy of their statements? and if we had no doubt of their veracity, might we not expect them to

* Elements, pp. 430–440.

† Only two species of Purbeck mammals discovered by Mr. Brodie and referred by Prof. Owen to his genus *Spalacotherium*, were known before the year 1856, when Mr. S. H. Beckles sent me a collection of fossils, which I submitted to Dr. Falconer. From his interpretation of these remains, chiefly of lower jaws, I was enabled to announce in 1857, in the supplement to my Manual or Elements of Geology, that no less than fourteen species of mammalia, referable to eight or nine genera, had then been obtained from a stratum a few inches thick of the Middle Purbeck, all within an area of 500 square yards. This number has now been increased to no less than twenty-five species, referable to eleven genera, and the whole of them admirably described and figured in a Monograph of the Palæontographical Society, 1871, by Prof. Owen. See also Elements, 6th ed., p. 379; and Student's Elements, 1871, p. 303.

be unskilled naturalists? or, if the fact were unquestioned, should we not be disposed to believe that some vessel had been wrecked on the spot?

The casualties must always be rare by which land quadrupeds are swept by rivers far out into the open sea, and still rarer the contingency of such a floating body not being devoured by sharks or other predaceous fish, such as were those of which we find the teeth preserved in some of the carboniferous strata; but if the carcase should escape, and should happen to sink where sediment was in the act of accumulating, and if the numerous causes of subsequent disintegration should not efface all traces of the body, included for countless ages in solid rock, it would be contrary to all calculation of chances that we should hit upon the exact spot, that mere point in the bed of an ancient ocean, where the precious relic was entombed. Can we expect for a moment, when we have only succeeded, amidst several thousand fragments of corals and shells, in finding a few bones of *aquatic* vertebrata, that we should meet with a single skeleton of an inhabitant of the land?

Clarence, in his dream, saw 'in the slimy bottom of the deep,'

> ——a thousand fearful wrecks;
> A thousand men, that fishes gnawed upon;
> Wedges of gold, great anchors, heaps of pearl.

Had he also beheld, amid 'the dead bones that lay scattered by,' the carcases of lions, deer, and the other wild tenants of the forest and the plain, the fiction would have been deemed unworthy of the genius of Shakespeare. So daring a disregard of probability and violation of analogy would have been condemned as unpardonable, even where the poet was painting those incongruous images which present themselves to a disturbed imagination during the visions of the night.

Absence of Cetacea in Secondary rocks.—But there is a negative fact of great significance which seems more than any other to render it highly improbable that we shall ever find air-breathers of the highest class in any of the primary strata, or in any of the older members of the secondary series.

This fact is the absence hitherto of all bones of cetacea among the numerous remains of fossil vertebrata entombed in rocks older than the Eocene. Cetacean bones are of rare occurrence in the Lower Tertiary formations of Europe, the only instance in Great Britain being a species of Monodon from the London clay, and the position even of this specimen is somewhat doubtful. But in the middle Eocene of America, as in Georgia and Alabama, the gigantic *Zeuglodon*, now admitted to be a true placental mammal, is by no means of uncommon occurrence.* The dimensions of the cetacea in general are such that they could hardly have failed to obtrude themselves on the notice of collectors had they been entombed in the mud and sand of Triassic, Liassic, or other secondary formations where the skeletons of huge reptiles are so conspicuous. The ichthyosaurs and other carnivorous saurians seem formerly to have played the part now assigned to the cetacea in the economy of nature; and if we assume this to have been the case, it seems probable that the placental mammalia, if they existed at all before the Tertiary period, were at least extremely scarce.

Successive appearance in chronological order of the great sub-classes of mammalia of higher and higher grade.—In a classification of mammalia, founded on the modification of their cerebral structure, Professor Owen has assigned the lowest place to a sub-class called Lyencephala, which comprises two orders, the Marsupialia and the Monotremata. In this last are included the *Echidna* (or duckbilled Platypus) of Australia and the *Ornithorhynchus* of the same continent. No members of this lowest division of the mammalia have yet been found fossil, but we ought to look for their remains in the Carboniferous and other primary rocks, should air-breathers higher than the class of reptiles ever be discovered in them, assuming that a thorough knowledge of the succession in time of the fossil vertebrata would bear out fully the theory of progressive development from the simplest to the most complex types. We should then have

* The supposed cetaceans of the cretaceous rocks, which I formerly cited on the authority of Dr. Leidy, have lately been ascertained by him to be of Miocene date.—Leidy, Reptiles of the Chalk.

monotremata in the Primary, marsupials in the Secondary, and placentals in the Tertiary strata, assuming for the present that the class to which *Stereognathus* belongs is still undetermined.

In the history of the Tertiary and Post-Tertiary series, it may be said that there is in the mammalia a still farther evolution from the less to the more perfect structures. For the earliest known species of the placental sub-class does not belong to the Quadrumanous order, the most ancient representative of that sub-class being the *Arctocyon primævus*, a mammal allied to the bear, which has been met with in France in Eocene strata older than the Plastic clay or Woolwich beds. Of later date than this, M. Rütimeyer has recognised, in a member of the Middle Eocene group of the Swiss Jura, the jawbone of a monkey allied in some points to the Mycetes or howling monkey of America and in others to the Lemurs. If this determination be confirmed when more of the skeleton has been discovered, the *Cœnopithecus lemuroides* would constitute the oldest known example of a fossil quadrumanous animal.* The next step occurs in the Upper Miocene or Falunian deposits of Europe, in which several examples of the monkey tribe have been met with, and among them some of the *anthropomorphous* apes. One of them, the *Dryopithecus*, allied to the Gibbon, discovered in the South of France, rivalled man in stature. If in the Pliocene strata, which followed next in the order of time, no quadrumana have been detected, we may attribute their absence to the diminished warmth of the Pliocene climate, which began to resemble that now enjoyed in the south of Europe, instead of being, like that of the Upper Miocene, sub-tropical. For evidence of the gradual development of the monkeys, apes, and orangs, and of the first appearance of man, the progressionist will naturally look to those countries which escaped the rigours of the Glacial period, whereas our most careful investigations have hitherto been

* The fossil monkey named Macacus Eocenus by Owen, found in 1840, at Kyson, near Ipswich in Suffolk, in a stratum older than the London clay, and which I formerly cited as quadrumanous on the authority of Prof. Owen, was pronounced by the same anatomist in 1862 to be a pachyderm, more ample data for its correct determination having been obtained.

confined to the temperate latitudes of the northern hemisphere, whether in the Old or New World. However slender therefore may be the foundation of facts on which such grand generalisations are built, and however anxious we may be not to place too much reliance on the soundness of our inferences, we may yet say that the direction in which the facts point are decidedly towards the theory of progression. It may no doubt be said that the entire area from which the Secondary or Mesozoic species of mammalia, thirty-three in number, have been obtained is confined to a very limited part of the globe, even when we include the site of the Dromatherium of North Carolina, between three and four thousand miles distant from Stuttgardt. But on the other hand we must recollect that the time throughout which this fauna has been traced is of vast duration, extending from the Rhœtic or Upper Triassic beds to those which form the Purbeck or last stage of the great Oolitic era. In Australia at present, out of more than two hundred living species of mammalia above three-fourths are marsupial, and the remaining species are confined to the orders of bats and rodents which are small in size and belong to the Lissencephala or lowest sub-class of placental mammalia, when classified according to cerebral development. In the ancient strata of Mesozoic age so far as yet known we also find a predominance of undoubted marsupials, associated with some species which may perhaps be placental, but which, if so, are diminutive in size, and belonging to orders of a low grade in that class. During the long period throughout which this mammalian fauna was persistent, there were abundance of terrestrial and aquatic reptiles, and the species both of the vertebrate and invertebrate classes were frequently changing, so that the absence of a single cetacean, or other representative of the Gyrencephalous orders can hardly be regarded as wholly accidental, or attributed entirely to our limited acquaintance with the air-breathers of the period in question. We may at least affirm that, in the present state of our knowledge, a comparison of this mammalian fauna with that of the Tertiary era which succeeded it next in

chronological order, points to a law of progressive development from the more simple to the more complex.

We have then been fairly led by palæontological researches to the conclusion that the invertebrate animals flourished before the vertebrata, and that in the latter class fish, reptiles, birds, and mammalia made their appearance in a chronological order analogous to that in which they would be arranged zoologically according to an advancing scale of perfection in their organisation. In regard to the mammalia themselves, they have been divided by Professor Owen, in the classification already alluded to (p. 161), into four sub-classes by reference to modifications of their brain. In the two lowest, called Lyencephala and Lissencephala, are included the marsupials and insectivora, and these have been met with fossil in the secondary rocks. Next above them in grade are the Gyrencephala, in which Cetaceans, Proboscidians, Ruminants, Carnivora, and Quadrumana are classed, all of which are found fossil in tertiary strata. Among these the Quadrumana rank highest, and the Anthropomorphous family takes the lead in organisation and instinct among the Quadrumana, coming also last in the order of time. To crown the whole, the series ends with the fourth great sub-class, the Archencephala, of which man is the sole representative, and of which the fossil remains have not yet been detected in deposits older than the post-tertiary.

Antecedently to investigation, we might reasonably have anticipated that the vestiges of man would have been traced back at least as far as those Pliocene strata in which nearly all the testacea and a certain number of the mammalia are of existing species, for of all the mammalia the human species is the most cosmopolite, and perhaps more capable than any other of surviving considerable vicissitudes in climate, and in the physical geography of the globe.

No inhabitant of the land exposes himself to so many dangers on the waters as man, whether in a savage or a civilised state; and there is no animal, therefore, whose skeleton is so liable to become imbedded in lacustrine or submarine deposits: nor can it be said that his remains are more perishable than those of other animals; for in ancient

fields of battle, as Cuvier has observed, the bones of men have suffered as little decomposition as those of horses which were buried in the same grave. But even if the more solid parts of our species had disappeared, the impression of their form might have remained engraven on the rocks, as have the traces of the tenderest leaves of plants, and the soft integuments of many animals. Works of art, moreover, composed of the most indestructible materials, would have outlasted almost all the organic contents of sedimentary rocks. Edifices, and even entire cities, have, within the times of history, been buried under volcanic ejections, submerged beneath the sea, or engulphed by earthquakes; and had these catastrophes been repeated throughout an indefinite lapse of ages, the high antiquity of man would have been inscribed in far more legible characters on the framework of the globe than are the forms of the ancient vegetation which once covered the islands of the northern ocean, or of those gigantic reptiles which at still later periods peopled the seas and rivers of the northern hemisphere.

Introduction of Man, to what extent a change of the system. —I shall defer to the next volume the discussion of a theoretical question of surpassing interest with which the palæontologist has been busily engaged ever since the time of Lamarck, namely, whether it is conceivable that each fossil fauna and flora brought to light by the geologist may have been connected, by way of descent or generation, with that which immediately preceded it, our record being so defective that nearly all the intermediate links by which a transition was effected from genus to genus, or from species to species, have in most cases left behind them no vestiges of their former existence. In support of this opinion, it has been argued that the earliest remains of man imply a rude state of the arts and an entire ignorance of the use of metals. On the other hand, little or no progress has been made in discovering fossil remains which indicate any inferiority in the cerebral development of the men who were contemporary with the mammoth, and were the fabricators of the earliest known stone weapons. It may fairly be argued that the superiority of man depends, not on those faculties and

attributes which he shares in common with the lower animals, but on his reason, by which he is distinguished from them. When it is said that the human race is of far higher dignity than were any pre-existing beings on the earth, it is the intellectual and moral attributes of our race, rather than the physical, which are considered; and it is by no means clear that the organisation of man is such as would confer a decided pre-eminence upon him, if, in place of his reasoning powers, he was merely provided with such instincts as are possessed by the lower animals. Without entering at present into the discussion of this and other cognate questions, we may endeavour to answer an objection which has been made to the doctrine of the past uniformity of nature.

Is not the interference of the human species, it is asked, such a deviation from the antecedent course of physical events that the knowledge of such a fact tends to destroy all our confidence in the uniformity of the order of nature, both in regard to time past and future? If such an innovation could take place after the earth had been exclusively inhabited for thousands of ages by inferior animals, why should not other changes as extraordinary and unprecedented happen from time to time? If one new cause was permitted to supervene, differing in kind and energy from any before in operation, why may not others have come into action at different epochs? Or what security have we that they may not arise hereafter? And if such be the case, how can the experience of one period, even though we are acquainted with all the possible effects of the then existing causes, be a standard to which we can refer all natural phenomena of other periods?

Now these objections would be unanswerable, if adduced against one who was contending for the absolute uniformity throughout all time of the succession of sublunary events—if, for example, he was disposed to indulge in the philosophical reveries of some Egyptian and Greek sects, who represented all the changes both of the moral and material world as repeated at distant intervals, so as to follow each other in their former connection of place and time. For they compared the course of events on our globe to astronomical cycles; and not only did they consider all sublunary affairs to be under the

influence of the celestial bodies, but they taught that on the earth, as well as in the heavens, the same identical phenomena recurred again and again in a perpetual vicissitude. The same individual men were doomed to be re-born, and to perform the same actions as before: the same arts were to be invented, and the same cities built and destroyed. The Argonautic expedition was destined to sail again with the same heroes, and Achilles with his Myrmidons to renew the combat before the walls of Troy.

> Alter erit tum Tiphys, et altera quæ vehat Argo
> Dilectos heroas; erunt etiam altera bella,
> Atque iterum ad Trojam magnus mittetur Achilles.*

The geologist, however, may condemn these tenets as absurd, without running into the opposite extreme, and denying that the order of nature has, from the earliest periods, been uniform in the same sense in which we believe it to be uniform at present, and expect it to remain so in future. We have no reason to suppose, that when man first became master of a small part of the globe, a greater change took place in its physical condition than is now experienced when districts, never before inhabited, become successively occupied by new settlers. When a powerful European colony lands on the shores of Australia, and introduces at once those arts which it has required many centuries to mature; when it imports a multitude of plants and large animals from the opposite extremity of the earth, and begins rapidly to extirpate many of the indigenous species, a mightier revolution is effected in a brief period than the first entrance of a savage horde, or their continued occupation of the country for many centuries, can possibly be imagined to have produced. If there be no impropriety in assuming that the system is uniform when disturbances so unprecedented occur in certain localities, we can with much greater confidence apply the same language to those primeval ages when the aggregate number and power of the human race, or the rate of their advancement in civilisation, must be supposed to have been far inferior. In

* Virgil, Eclog. iv. For an account of these doctrines, see Dugald Stewart's Elements of the Philosophy of the Human Mind, vol. ii. chap. ii. sect. 4; and Prichard's Egypt. Mythol. p. 177.

reasoning on the state of the globe before the existence of man, we must be guided by the same rules of induction as when we speculate on the state of America in the interval that elapsed between the introduction of man into Asia, the supposed cradle of our race, and the arrival of the first adventurers on the shores of the New World. In that interval, we imagine the state of things to have gone on according to the order now observed in regions unoccupied by man. Even now, the waters of lakes, seas, and the great ocean, which teem with life, may be said to have no immediate relation to the human race—to be portions of the terrestrial system of which man has never taken, nor ever can take, possession; so that the greater part of the inhabited surface of the planet may still remain almost as insensible to our presence as before any isle or continent was appointed to be our residence.

If the barren soil around Sydney had at once become fertile upon the landing of our first settlers; if, like the happy isles whereof the poets have given us such glowing descriptions, those sandy tracts had begun to yield spontaneously an annual supply of grain, we might then, indeed, have fancied alterations still more remarkable in the economy of nature to have attended the first coming of our species into the planet. Or if, when a volcanic island like Ischia was, for the first time, brought under cultivation by the enterprise and industry of a Greek colony, the internal fire had become dormant, and the earthquake had remitted its destructive violence, there would then have been some ground for speculating on the debilitation of the subterranean forces, when the earth was first placed under the dominion of man. But after a long interval of rest, the volcano bursts forth again with renewed energy, annihilates one-half of the inhabitants, and compels the remainder to emigrate. The course of nature remains evidently unchanged; and, in like manner, we may suppose the general condition of the globe, immediately before and after the period when our species first began to exist, to have been the same, with the exception only of man's presence.

The modifications in the system of which man is the

instrument do not, perhaps, constitute so great a deviation from previous analogy as we usually imagine; we often, for example, form an exaggerated estimate of the extent of our power in extirpating some of the inferior animals, and causing others to multiply; a power which is circumscribed within certain limits, and which is by no means exclusively exerted by our species.* The growth of human population cannot take place without diminishing the numbers, or causing the entire destruction, of many animals. The larger beasts of prey in particular give way before us; but other quadrupeds of smaller size, and innumerable birds, insects, and plants, which are inimical to our interests, increase in spite of us, some attacking our food, others our raiment and persons, and others interfering with our agricultural and horticultural labours. We behold the rich harvest which we have raised by the sweat of our brow, devoured by myriads of insects, and are often as incapable of arresting their depredations, as of staying the shock of an earthquake, or the course of a stream of lava.

A great philosopher has observed, that we can command Nature only by obeying her laws; and this principle is true even in regard to the astonishing changes which are superinduced in the qualities of certain animals and plants by domestication and garden culture. I shall point out in the next volume that we can only effect such surprising alterations by assisting the development of certain instincts, or by availing ourselves of that mysterious law of their organisation, by which individual peculiarities are transmissible from one generation to another.†

It is probable, from these and many other considerations, that as we enlarge our knowledge of the system, we shall become more and more convinced, that the alterations caused by the interference of man deviate far less from the analogy of those effected by other animals than is usually supposed.‡ We are often misled, when we institute such comparisons, by our knowledge of the wide distinction between the instincts of animals and the reasoning power of man; and we are apt

* See Ch. XLII.

† See Ch. XXXVI.

‡ See Ch. XXXVIII., XXXIX., XL., XLII.

hastily to infer, that the effects of a rational and irrational species, considered merely *as physical agents*, will differ almost as much as the faculties by which their actions are directed.

It is not, however, meant by the foregoing observations to convey the idea, that a real departure from the antecedent course of physical events cannot be traced in the introduction of man. If that latitude of action which enables the brutes to accommodate themselves in some measure to accidental circumstances could be imagined to have been at any former period so great that the operations of instinct were as much diversified as are those of human reason, it might, perhaps, be contended, that the agency of man did not constitute an essential deviation from the previously established order of things. It might then have been said that the advent of man upon the earth was an era in the moral, not in the physical world—that our study and contemplation of the earth, and the laws which govern its animate productions, ought no more to be considered in the light of a disturbance or deviation from the system, than the discovery of the satellites of Jupiter should be regarded as a physical event affecting those heavenly bodies. Their influence in advancing the progress of science among men, and in aiding navigation and commerce, was accompanied by no reciprocal action of the human mind upon the economy of nature in those distant planets; and so the earth might be conceived to have become, at a certain period, a place of moral discipline and intellectual improvement to man, without the slightest derangement of a previously existing order of change in its animate and inanimate productions.

The distinctness, however, of the human from all other species, considered merely as an efficient cause in the physical world, is real; for we stand in a relation to contemporary species of animals and plants widely different from that which irrational animals can ever be supposed to have held to each other. We modify their instincts, relative numbers, and geographical distribution, in a manner superior in degree, and in some respects very different in kind, from that in which any other species can affect the rest. Besides, the progressive movement of each successive generation of men

causes the human species to differ more from itself in power and intelligence at two distant periods, than any one species of the higher order of animals differs from another. The establishment, therefore, by geological evidence, of the intervention of such a peculiar and unprecedented agency, long after other parts of the animate and inanimate world existed, affords ground for concluding that the experience during thousands of ages of all the events which may happen on this globe, would not enable a philosopher to speculate with confidence concerning future contingencies. But his reliance need not be shaken in the unvarying constancy of the laws of nature, or in his power of reasoning from the present to the past in regard to the changes of the terrestrial system, whether in the organic or inorganic world, provided that he does not deny, in the organic world at least, the possibility of a law of evolution and progress.

CHAPTER X.

FURTHER CONSIDERATION OF THE AGREEMENT OF THE ANCIENT AND MODERN CAUSES OF CHANGE—VICISSITUDES IN CLIMATE.

ARGUMENTS DERIVED FROM FORMER DIFFERENCES IN CLIMATE—THE REALITY OF SUCH FORMER DIFFERENCES CONSIDERED—CLIMATE OF THE AGES OF BRONZE AND OF STONE—FOSSIL QUADRUPEDS AND SHELLS OF THE DRIFT—TEMPERATURE IMPLIED BY THE REMAINS OF THE MAMMOTH AND OTHER EXTINCT QUADRUPEDS—CARCASES OF THE ELEPHANT AND RHINOCEROS PRESERVED IN THE FROZEN MUD OF SIBERIA—IMPORTANT BEARING OF THE CONDITION OF THESE FOSSIL REMAINS ON THE THEORY OF CLIMATE—VARIATION IN THE TEMPERATURE OF POST-GLACIAL TIMES—ORGANIC AND INORGANIC PROOFS OF GREAT COLD IN THE GLACIAL EPOCH—INTER-GLACIAL PERIODS OF DÜRNTEN AND CROMER—BRITISH PLIOCENE STRATA, SHOWING TRANSITION FROM WARMER TO COLDER CLIMATE—THE SIGNS OF WARM TEMPERATURE AFFORDED BY ITALIAN PLIOCENE STRATA—WARM CLIMATE OF CENTRAL EUROPE IN UPPER MIOCENE TIMES—REPTILES AND QUADRUMANA—FOSSILS OF THE SIWÂLIK HILLS—UPPER MIOCENE STRATA OF WEST INDIES—WARM CLIMATE IMPLIED BY LOWER MIOCENE FAUNA AND FLORA—MIOCENE FOREST TREES IN HIGH ARCTIC LATITUDES—HIGH TEMPERATURE OF THE EOCENE PERIOD—SUPPOSED SIGNS OF ICE-ACTION IMPLIED BY ERRATIC BLOCKS OF UPPER MIOCENE AND MIDDLE EOCENE CONGLOMERATES.

Climate of the Northern Hemisphere formerly different.—ANOTHER objection to the theory which endeavours to explain all geological changes by reference to causes now in action is founded on the former prevalence of climates hotter than those now experienced in corresponding latitudes. We have seen (p. 41) that Hooke, about the year 1688, grounded his belief in the reality of the higher temperature of the waters of the ancient sea on the occurrence of fossil turtles and ammonites in the Portland oolite. In later times the shells and corals of the other fossiliferous strata, some older and some newer than this Secondary or Mesozoic rock, were appealed to as confirmatory of the same conclusions, whilst the botanist referred to the character of the fossil flora of the ancient carboniferous rocks as favourable to the same doctrine.

All indications of a high temperature recognised in the older formations were the more readily accepted because they seemed to lend support to the hypothesis of the primeval igneous fusion of the planet, the mass of which, while it radiated heat into the surrounding atmosphere and ocean, had gradually cooled, and had been constantly acquiring a thicker crust.

Since I first attempted, in the year 1830, to account for vicissitudes of climate by reference to changes in the physical geography of the globe,* our knowledge of the subject has greatly increased, and the problem to be solved has assumed a somewhat new aspect. More extended observations have shown that in times past the climate of the extra-tropical regions has by no means been always hotter than now, but, on the contrary, there has been at least one period, and one of very modern date geologically speaking, when the temperature of those regions was much lower than at present. It will be desirable, therefore, before entering into a discussion of the probable causes of the changes of temperature which have been experienced since the earliest of the fossiliferous rocks were formed, to lay before the reader a brief account of the evidence by which the reality of such changes has been established.

At first sight it may seem to be the simplest way of dealing with this subject to begin with a description of the proofs deduced from organic remains of the state of things in very remote times, and then to pass on to successive variations in climate manifested by the fauna and flora of later epochs. But such a method is impracticable, for not only are all the animals and plants found fossil in the oldest rocks specifically distinct from those now living, but a large part of the genera and not a few of the orders to which they belong have for ages ceased to exist. Consequently, when we attempt to make such a comparison with the view of determining the difference of the climates which prevailed at two distant periods, we find it almost impossible to apply the rules derived from the study of the present state of the animate world to another which differed from it so widely. The thread of

* Principles of Geology, 1st edition. 1830.

induction seems broken, and we become convinced that in order to make good our ground, and to reason securely from the known to the unknown, we must first ascertain the relation which the present organic creation bears to that of the period immediately antecedent, when the species of mollusca or those fossils with which we have most to deal were nearly all identical, and then carry back our retrospect step by step to formations of older date. In adopting this course we have the advantage of comparing, in the first instance, the species now in being, of which the habits and physiological characters are known, with the animal and vegetable remains entombed in the Tertiary formations, in which, as we have seen in the last chapter, all the classes of animals and plants are represented in proportions very analogous to those now prevailing. By this means we escape the danger of one source of error, namely, that of ascribing the predominance of certain genera or families to a difference in climate while in reality this predominance may have depended not on temperature, but on the absence of competing tribes of higher grade, which, according to the law of progressive development, had not yet made their appearance on the earth.

Climate of the Ages of Bronze and of Stone.—In pursuance, then, of this method of enquiry, we may consider, in the first place, the climate of Europe in times immediately anterior to the historical. We there find no indications of any marked divergence from the present condition of things, whether in the memorials of the age of bronze or in those of the Neolithic age,* which preceded it, namely, that to which the Danish kitchen-middens and many of the Swiss lake dwellings belonged.

It is evident that the plants and animals which co-existed with man in those ages were identical with species now living in the same countries, with the exception of a few known to have been locally extirpated in historical times.

The next antecedent era of which we have acquired any information is that designated by the late M. Lartet 'the

* Sir John Lubbock, in his 'Prehistoric Times,' p. 3, has proposed the term 'Neolithic' for this more modern age of stone, calling the older stone period, that in which man was contemporary with many extinct mammalia, 'Palæolithic.'

Reindeer period,' when that northern animal, together with several others fitted for a cold climate, extended its range to the foot of the Pyrenees. The mammoth and cave-lion, quadrupeds more characteristic of an anterior period, have been found sparingly in this fauna, and another extinct quadruped, the Irish elk or gigantic deer.* The weapons then in use by man show a rude state of the arts, and complete ignorance of the use of metals. Passing over this intermediate period, which is as yet but vaguely and imperfectly defined, we come to the older stone age, or 'Palæolithic Period,' comprising the ancient river-gravels of Amiens and Abbeville in France, and of Salisbury and Bedford in England, and the superficial deposits of many other parts of Europe. Here, for the first time in our retrospect, we encounter the bones of a large number of extinct species of the genera elephant, rhinoceros, bear, tiger, and hyæna, associated with the remains of living animals and of man. The human relics consist almost entirely in North-western Europe of unpolished flint implements of a type different from those of the later or Neolithic era, implying a less advanced state of civilisation. The gravels containing such works of art and bones of extinct animals belong to a time when some of the minor features of the physical geography were different from those now characterising the same part of Europe, a discordance which does not hold true of the more modern or Neolithic times. The valleys of the more ancient of the two periods had not acquired their present width, depth, and outline. The bones of man and rude works of art occur also in caves associated with the remains of mammalia similar to those of the palæolithic gravels above mentioned. The enormous volume of alluvial matter formed in the channels of the old rivers, the contorted stratification of some parts of such alluvium, and the large size of many of the transported stones which it contains, imply a climate which generated much snow and ice in winter, and a mean annual temperature lower than that now found in the same parts of Europe.† The fossil shells also imbedded

* See Mr. Boyd Dawkins' list of mammalia of the Dordogne Caves, Quart. Journ. of Sci., July 1866, p. 343.

† For contortions of the drift, see Antiquity of Man, by the Author, p. 138.

in the same deposits are all of species now living, and characteristic, with a few exceptions to be mentioned in the sequel, of Central and Northern Europe. The general absence of the bones of reptiles, even of those of small dimensions, is very significant, as indicating a former state of the atmosphere and of the waters uncongenial to that class of vertebrata.

Climate of the Mammoth and its associates.—Geologists, when they first examined the fossils of the drift, approached the subject with the fullest conviction on their minds that the climate of the globe in the olden times was warmer than it is now. This opinion they had legitimately derived from the study of the Tertiary and Secondary rocks, and when they encountered the bones of the elephant, rhinoceros, hippopotamus, lion, tiger, and hyæna plentifully entombed in the old river-gravels above mentioned, and in the contemporaneous mud and breccia of caverns, they concluded, without hesitation, that as all the genera alluded to are now characteristic of warmer latitudes, their presence was in perfect harmony with the received doctrine. The fact that the numerous land and fresh-water shells accompanying the same fossils were almost without exception identical with those now inhabiting the same country, ought doubtless to have served as a warning against the belief in a hotter climate; but the well-known forms of many large and conspicuous mammalia made a greater impression on their minds than the comparatively diminutive mollusca, with which few were familiar. The late Dr. Fleming, however, before the notion had gained ground that a glacial epoch had intervened between tertiary and historical times, called in question, in 1829, the opinion that the bones of the elephant and rhinoceros, and other associated pachyderms and beasts of prey, implied a tropical climate. A near resemblance, he observed, in form and osteological structure is not always followed in the existing mammiferous fauna by a similarity of geographical distribution; and we must therefore be on our guard against deciding too confidently, from mere analogy of anatomical structure, respecting the habits and physiological peculiarities of *species* now no more. 'The zebra,' he remarked, 'delights to roam over the tropical plains; while the horse can maintain its existence

throughout an Iceland winter. The buffalo, like the zebra, prefers a high temperature, and cannot thrive even where the common ox prospers. The musk-ox, on the other hand, though nearly resembling the buffalo, prefers the stinted herbage of the arctic regions, and is able, by its periodical migrations, to outlive a northern winter. The jackal (*Canis aureus*) inhabits Africa, the warmer parts of Asia, and Greece; while the isatis, or arctic fox (*Canis lagopus*), resides in the arctic regions. The African hare and the polar hare have their geographical distribution expressed in their trivial names;'* and different species of bears thrive in tropical, temperate, and arctic latitudes.

Other writers soon followed up the same line of argument, and Mr. Hodgson, among others, in his account of the mammalia of Nepal, stated that the tiger was sometimes found at the very edge of perpetual snow in the Himalaya.† Pennant had previously mentioned that it had been seen among the snows of Mount Ararat in Armenia, and later authorities have placed it beyond all doubt that a species of tiger identical with that of Bengal is common in the neighbourhood of Lake Aral, near Sussac, in the forty-fifth degree of North latitude. Humboldt remarks, that the part of Southern Asia now inhabited by this Indian species of tiger is separated from the Himalaya by two great chains of mountains, each covered with perpetual snow,—the chain of Kuenlun, lat. 35° N., and that of Mouztagh, lat. 42°,—so that it is impossible that these animals should merely have made excursions from India, so as to have penetrated in summer to the forty-eighth and fifty-third degrees of North latitude. They must remain all the winter north of the Mouztagh, or Celestial Mountains. The last tiger killed, in 1828, on the Lena, in lat. 52¼°, was in a climate colder than that of St. Petersburg and Stockholm.‡

A species of panther (*Felis irbis*), covered with long hair, has been discovered in Siberia, evidently inhabiting, like the

* Fleming, Ed. New Phil. Journ., No. xii. p. 282, 1829.

† Journ. of Asiat. Soc., vol. i. p. 240.

‡ Humboldt, Fragmens de Géologie, &c., tome ii. p. 388. Ehrenberg, Ann. des Sci. nat., tome xxi. pp. 387, 390.

tiger, a region north of the Celestial Mountains, which are in lat. 42°.*

In regard to the climate of the living elephant, the Rev. Robert Everest observes, that the greatest elevation at which it is found in a wild state is in the north-west Himalaya, at a place called Nahun, about 4,000 feet above the level of the sea, and in the 31st degree of N. lat., where the mean yearly temperature may be about 64° Fahrenheit, and the difference between winter and summer very great, equal to about 36° F., the month of January averaging 45°, and June, the hottest month, 91° F.†

Von Schrenck, writing in 1858, announced that in Amoorland, part of North-Eastern Asia, then recently annexed to the Russian Empire, no less than 34 out of 58 living quadrupeds are identical with European species. Among those which are not European, some are arctic, others of tropical forms; in illustration of which, he states that the Bengal tiger, ranging sometimes northwards as far as lat. 42°, subsists chiefly on the flesh of the reindeer, while, on the other hand, the small tailless hare or pika occasionally wanders from its polar haunts to parts of Amoorland as far south as 48°.‡ In America, the jaguar has been seen wandering from Mexico as far north as Kentucky, lat. 37° N.§, and in the opposite direction as far as 42° S. in South America,—a latitude which corresponds to that of the Pyrenees in the northern hemisphere.|| The range of the puma is still wider, for it roams from the equator to the Straits of Magellan, being often seen at Port Famine, in lat. 53° 38′ S. When the Cape of Good Hope was first colonised, the two-horned African rhinoceros was found in lat. 34° 29′ S., accompanied by the elephant, hippopotamus, and hyæna. Here the migration of all these species towards the south was arrested by the ocean; but if the African continent had been prolonged still farther, and the land had been of moderate elevation, it is highly

* Ehrenberg, Ann. des Sci. nat., tome xxi. pp. 387, 390.

† Everest on Climate of Foss. Eleph., Journ. of Asiat. Soc., No. 25, p. 21.

‡ Nat. Hist. Rev., vol. i. p. 12, 1861. Antiquity of Man, p. 158.

§ Rafinesque, Atlantic Journ., p. 18.

|| Darwin's Journal of Travels in South America, &c., 1832 to 1836, in Voyage of H.M.S. Beagle, p. 159.

probable that they might have extended their range to a greater distance from the tropics.

Now, if the Indian tiger can range in our own times to the southern borders of Siberia, or skirt the snows of the Himalaya, and if the puma can reach the fifty-third degree of latitude in South America, we may easily understand how large species of the same *genera* may once have inhabited Northern Europe. The mammoth (*E. primigenius*), already alluded to, as occurring fossil in England, was decidedly different from the two living species of elephants, one of which is limited to Asia, south of the 31° of N. lat., the other to Africa, where it extends, as before stated, as far south as the Cape of Good Hope. The bones of the fossil species are very widely spread over Europe and North America; but are nowhere in such profusion as in Siberia, particularly near the shores of the Frozen Ocean.

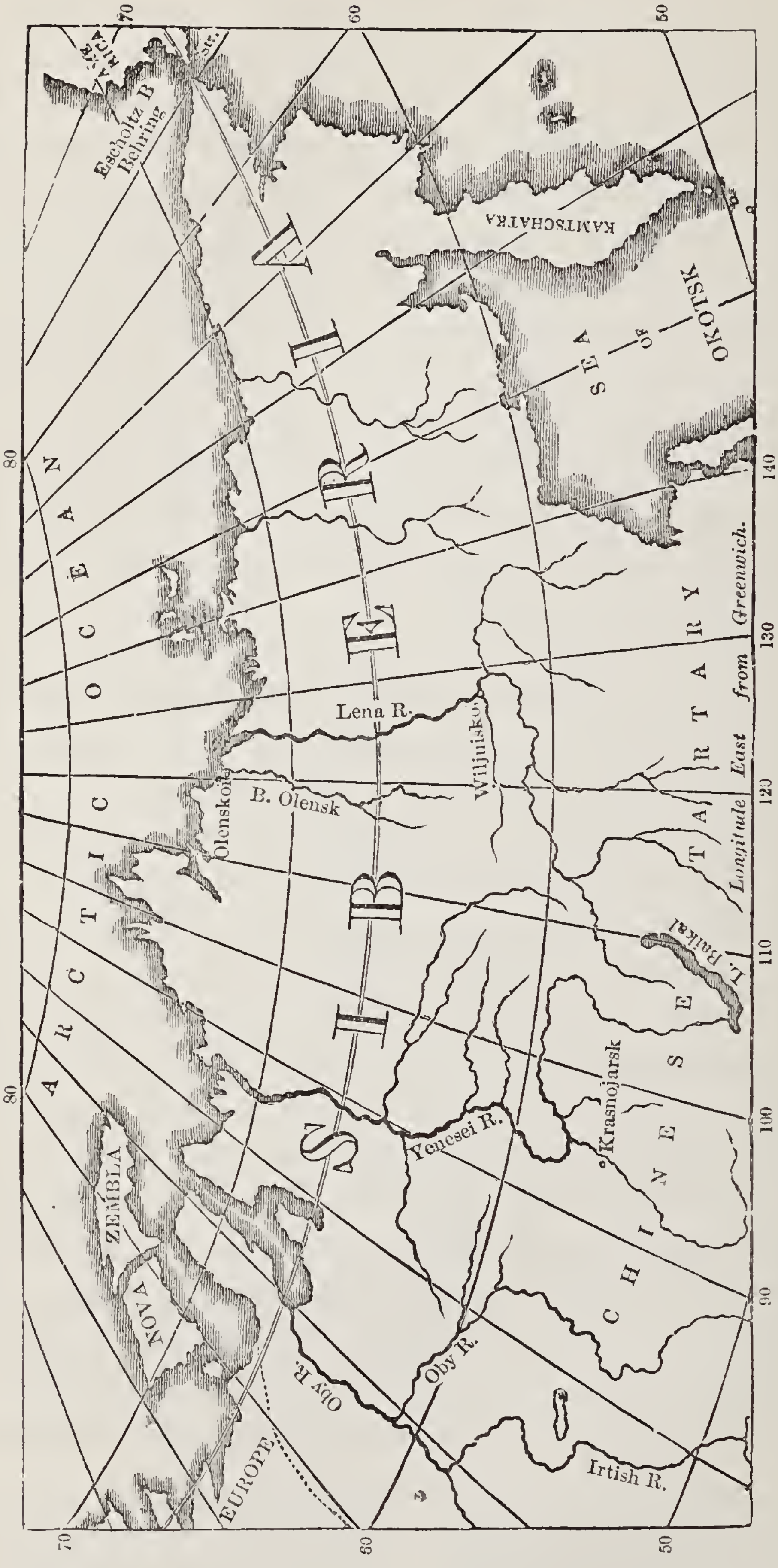
But if we are thence to conclude that this animal preferred a northern climate, it will naturally be asked, By what food was it sustained, and why does it not still survive near the Arctic circle?* Pallas and other writers describe the bones of the mammoth as occurring in a very fresh state throughout all the Lowland of Siberia, stretching in a direction west and east, from the borders of Europe to the extreme point nearest America, from south to north, from lat. 60° and from the base of the mountains of Central Asia to the shores of the Arctic Sea. (See map, fig. 7, p. 180.) Within this space, scarcely inferior in area to the whole of Europe, fossil ivory has been collected almost everywhere, on the banks of the Irtish, Obi, Yenesei, Lena, and other rivers. The elephantine remains do not occur in the marshes, but where the banks of the rivers present lofty precipices of sand and clay; from which circumstance Pallas very justly inferred that, if sections could be obtained, similar bones might be found in all the elevated lands intervening

* The speculations which follow, on the ancient physical geography of Siberia, and its former fitness as a residence for the mammoth, were first given in their present form in my 4th edition, June 1835. Sir R. Murchison and his companions, MM. de Verneuil and Keyserling, in their great work on the Geology of Russia, 1845 (vol. i. p. 497), have, in citing this chapter, declared that their investigations have led them to similar conclusions.

between the great rivers. Strahlenberg, indeed, had stated, before the time of Pallas, that wherever any of the great

Fig. 7.

MAP OF SIBERIA.



Map showing the course of the Siberian rivers from south to north, from temperate to arctic regions, in the country where the fossil bones of the mammoth abound.

rivers overflowed and cut out fresh channels during floods, more fossil remains of the same kind were invariably disclosed.

As to the position of the bones, Pallas found them in some places imbedded together with marine remains; in others, simply with fossil wood, or lignite, such as, he says, might have been derived from carbonised peat. On the banks of the Yenesei, below the city of Krasnojarsk, in lat. 56°, he observed grinders and bones of elephants, in strata of yellow and red loam, alternating with coarse sand and gravel, in which was also much petrified wood of the willow and other trees. Neither here nor in the neighbouring country were there any marine shells, but merely layers of black coal.* But grinders of the mammoth were collected much farther down the same river, near the sea, in lat. 70°, associated with *marine* remains.† Many other places in Siberia are cited by Pallas, where sea shells and fishes' teeth accompany the bones of the mammoth, rhinoceros, and Siberian buffalo, or bison (*Bos priscus*).

Carcasses of elephant and rhinoceros preserved in frozen mud.—But it is not on the Obi nor the Yenesei, but on the Lena, farther to the east, where in the same parallels of latitude, the cold is far more intense, that fossil remains were first found in the most wonderful state of preservation. In 1772, Pallas obtained from Wiljuiskoi, in lat. 64°, from the banks of the Wiljui, a tributary of the Lena, the carcass of a rhinoceros (*R. tichorhinus*), taken from the sand in which it must have remained congealed for ages, the soil of that region being always frozen to within a slight depth of the surface. This carcass, which was compared to a natural mummy, emitted an odour like putrid flesh, part of the skin being still covered with short crisp wool and with black and grey hairs. In allusion to the quantity of hair on the foot and head conveyed to St. Petersburg, Pallas asked whether this animal might not have inhabited a cold region of Middle Asia, its clothing being so much warmer than that of the African rhinoceros.‡

Professor Brandt, of St. Petersburg, in a letter to Baron Alex. Von Humboldt, dated 1846, adds the following particulars respecting this wonderful fossil relic:—'I have been

* Pallas, Reise im Russ. Reiche, pp. 409, 410.

† Nov. Com. Pétrop., vol. xvii. p. 584.

‡ Ibid. p. 591.

so fortunate as to extract from cavities in the molar teeth of the Wiljui rhinoceros a small quantity of its half-chewed food, among which fragments of pine-leaves, one-half of the seed of a polygonaceous plant, and very minute portions of wood with porous cells (or small fragments of coniferous wood), were still recognisable. It was also remarkable, on a close investigation of the head, that the blood-vessels discovered in the interior of the mass appeared filled, even to the capillary vessels, with a brown mass (coagulated blood), which in many places still showed the red colour of blood.' *

Thirty years after the discovery of the rhinoceros by Pallas, the entire carcass of a mammoth was obtained in 1803, by Mr. Adams, much farther to the north. It fell from a mass of ice, in which it had been encased, on the banks of the Lena, in lat. 70°; and so perfectly had the soft parts of the carcass been preserved, that the flesh, as it lay, was devoured by wolves and bears. This skeleton is still in the Museum of St. Petersburg, the head retaining its integument and many of the ligaments entire. The skin of the animal was covered, first, with black bristles, thicker than horse-hair, from twelve to sixteen inches in length; secondly, with hair of a reddish-brown colour, about four inches long; and thirdly, with wool of the same colour as the hair, about an inch in length. Of the fur, upwards of thirty pounds' weight were gathered from the wet sandbank. The individual was nine feet high and sixteen feet long, without reckoning the large curved tusks; a size rarely surpassed by the largest living male elephants.†

It is evident, then, that the mammoth, instead of being naked, like the living Indian and African elephants, was enveloped in a thick shaggy covering of fur, probably as impenetrable to rain and cold as that of the musk-ox.‡ The species may, as Cuvier observed,§ have been fitted by nature to withstand the vicissitudes of a northern climate; and it is certain that, from the moment when the carcasses, both of

* Quart. Journ. Geol. Soc. Lond., vol. iv. p. 10, Memoirs.

† Journal du Nord, St. Petersburg, 1807.

‡ Fleming, Ed. New Phil. Journ., No. xii. p. 285, 1829.

§ Ossements fossils, 4th ed., 1836.

the rhinoceros and elephant, above described, were buried in Siberia, in latitudes 64° and 70° N., the soil must have remained frozen, and the atmosphere as cold as at this day. The discoveries made in 1843 by Mr. Middendorf, a distinguished Russian naturalist, and which he communicated to me in September 1846, afford more precise information as to the climate of the Siberian Lowlands, at the period when the extinct quadrupeds were entombed. One elephant was found on the Tas, between the Obi and Yenesei, near the Arctic circle, about lat. 66° 30′ N., with some parts of the flesh in so perfect a state that the ball of the eye is now preserved in the Museum at Moscow. Another carcass, together with a young individual of the same species, was met with in the same year, 1843, in lat. 75° 15′ N., near the river Taimyr, with the flesh decayed. It was imbedded in strata of clay and sand, with erratic blocks, at about fifteen feet above the level of the sea. In the same deposit Mr. Middendorf observed the trunk of a larch-tree (*Pinus larix*), the same wood as that now carried down in abundance by the Taimyr to the Arctic Sea. There were also associated marine shells of *living northern* species, and which are moreover characteristic of the drift or *glacial* deposits of Scotland and other parts of Europe. Among these, *Nucula pygmæa, Tellina calcarea, Mya truncata*, and *Saxicava rugosa* were conspicuous.

So fresh is the ivory throughout Northern Russia, that, according to Tilesius, thousands of fossil tusks have been collected and used in turning; yet others are still procured and sold in great plenty. He declares his belief that the bones still left in Northern Russia must greatly exceed in number those of all the elephants now living on the globe.

Remains of the mammoth have been collected from the cliffs of frozen mud and ice on the east side of Behring's Straits, in Eschscholtz Bay, in Russian America, lat. 66° N. As the cliffs waste away by the thawing of the ice, tusks and bones fall out, and a strong odour of animal matter is exhaled from the mud.*

In 1866, in the flat country near the mouths of the Yenesei, between lat. 70° and 75° N., many skeletons of mammoths

* See Dr. Buckland's description of these bones, Appen. to Beechy's Voyage.

were found retaining the skin and hair. The heads of most of them are said to have been turned towards the south. So late as 1869–70, an exploring expedition was made by Herr von Maydell, under the direction of the Academy of St. Petersburg, to the river Indigiska, to examine some remains said to have been discovered there. We learn from M. Brandt * that the travellers found the skin and hair as well as the bones of the *Elephas primigenius* at two points on the river, about thirty miles distant from each other, and sixty-six miles from the Arctic Sea. In one of the localities a perfect skull also was dug out. The preservation of these and other individuals before mentioned in ice or frozen mud is a fact which has a most important bearing on all speculations concerning the climate of the Arctic regions, both at the time when these animals existed, and throughout the whole period which has since elapsed. There may have been oscillations of temperature, accompanying changes in the geography of the globe, or partly due to distinct phases of the precession of the equinoxes, or to various states of the ellipticity of the earth's orbit since the era in question; but one thing is clear, that the ice or congealed mud in which the bodies of such quadrupeds were enveloped has never once been melted since the day when they perished, so as to allow the free percolation of water through the matrix, for, had this been the case, the soft parts of the animals could not have remained undecomposed.

Rome is the most southern limit to which the fossil bones of the mammoth have as yet been traced in Europe. Some were detected in 1858 in Monte Sacro, in the environs of Rome, where they were recognised by M. Lartet among the mammalian remains obtained by Professor Ponzi from the volcanic gravel of that locality. Other specimens, as I learn from M. de Verneuil, have since been found in ancient alluvium on the banks of the Tiber, at Ponte Molle, associated with flint implements of contemporaneous date.

We are not obliged, says Dr. Falconer, to suppose that this ancient elephant, which in Europe extended its range

* Bull. de l'Acad. Imp. des Sciences St. Petersburg, vol. xv. p. 347.

from the Tiber to the Lena, and in North America from Eschscholtz Bay to the Gulf of Mexico, was enveloped in every latitude with a thick covering of fur. 'The fine silky fleece with which the domestic goat is clothed on the plains of Tibet, where the winter, at a height of 16,000 feet above the sea, is most severe, disappears entirely from the same animal in the valley of Cashmere.'*

Dr. Fleming, long before the discovery above alluded to by Brandt, of fossil pine-leaves in the molar of a Siberian rhinoceros, had hinted, that 'the kind of food which the existing species of elephant prefers will not enable us to determine, or even to offer a probable conjecture, concerning that of the extinct species. No one,' he said, 'acquainted with the gramineous character of the food of our fallow-deer, stag, or roe, would have assigned a lichen to the reindeer.'

Travellers mention that, even now, when the climate of Eastern Asia is so much colder than the same parallels of latitude farther west, there are woods not only of fir, but of birch, poplar, and alder, on the banks of the Lena, as far north as latitude 69° 5′.†

Professor Owen observes, that the teeth of the mammoth differ from those of the living elephants, whether Asiatic or African, having a larger proportion of dense enamel, which may have enabled it to subsist on the coarser ligneous tissues of trees and shrubs. In short, he is of opinion, that the structure of its teeth, as well as the nature of its epidermis and coverings, may have made it 'a meet companion for the reindeer.'

It has been suggested, that as, in our own times, the northern animals migrate, so the Siberian elephant and rhinoceros may have wandered towards the north in summer. The musk-oxen annually desert their winter quarters in the south, and cross the sea upon the ice, to graze for four months, from May to September, on the rich pasturage of Melville Island, in lat. 75°. The mammoth may in like manner have made excursions, during the warmth of a northern summer, from the central or temperate parts of

* Falconer, American Fossil Elephant, Nat. Hist. Rev., vol. iii. 1863.

† History of British Fossil Mammalia, 1844, p. 261 *et seq.*

Asia to the 75th parallel of latitude, even though the continuous land may not have extended so far.

If such were the case, the preservation of their bones, or even occasionally of their entire carcasses, in ice or frozen soil, may be accounted for, without resorting to speculations concerning sudden revolutions in the former state and climate of the earth's surface. We seem entitled to assume, that, in the time of the extinct elephant and rhinoceros, the Lowland of Siberia stretched less far towards the north than now; for we have seen (p. 181) that the strata of this Lowland, in which the fossil bones lie buried, were originally deposited beneath the sea; and we know, from the facts brought to light in Wrangel's Voyage, in the years 1821, 1822, and 1823, that a slow upheaval of the land along the borders of the Icy Sea is now constantly taking place, similar to that experienced in part of Sweden. In the same manner, then, as additions have been made to the shores of the Gulf of Bothnia, not only by the influx of sediment brought down by rivers, but also by the elevation and consequent drying up of the bed of the sea, so a like combination of causes may, in modern times, have been extending the low tract of land where marine shells of arctic species now existing and fossil bones occur in Siberia. In fact, the observations of Sir R. Murchison and other travellers have shown that such an extension has actually taken place. Such a change in the physical geography of that region, implying a constant augmentation in the quantity of arctic land, would, according to principles to be explained in the twelfth chapter, tend to increase the severity of the winters, and, by limiting the supply of food, finally contribute to the extermination of the mammoth and its contemporaries.

On referring to the map (p. 180), the reader will see how all the great rivers of Siberia flow at present from south to north, from temperate to arctic regions, and they are all liable, like the Mackenzie, in North America, to remarkable floods, in consequence of flowing in this direction. For they are filled with running water in their upper or southern course when still frozen over for several hundred miles near their mouth, where they remain blocked up by ice for six

months in every year. The descending waters, therefore, finding no open channel, rush over the ice, often changing their direction, and sweeping along forests and prodigious quantities of soil and gravel mixed with ice. Now the rivers of Siberia are among the largest in the world, the Yenesei having a course of 2,500, the Lena of 2,000 miles; so that we may easily conceive that the bodies of animals which fall into their waters may be transported to vast distances towards the Arctic Sea, and, before arriving there, may be stranded upon and often frozen into thick ice. Afterwards, when the ice breaks up, they may be floated still farther towards the ocean, until at length they become buried in fluviatile and submarine deposits near the mouths of rivers.

Humboldt remarks that near the mouths of the Lena a considerable thickness of frozen soil may be found at all seasons at the depth of a few feet; so that if a carcass be once imbedded in mud and ice in such a region and in such a climate, its putrefaction may be arrested for indefinite ages.* According to Professor Von Baer of St. Petersburg, the ground is now frozen permanently to the depth of 400 feet at the town of Yakutzk, on the western bank of the Lena, in lat. 62° N., 600 miles distant from the Polar Sea. Mr. Hedenstrom tells us that, throughout a wide area in Siberia, the boundary cliffs of the lakes and rivers consist of alternate layers of earthy materials and ice, in horizontal stratification;† and Mr. Middendorf told me in 1846, that, in his tour there three years before, he had bored in Siberia to the depth of seventy feet, and, after passing through much frozen soil mixed with ice, had come down upon a solid mass of pure transparent ice, the thickness of which, after penetrating two or three yards, they did not ascertain.

The late Sir John Richardson informed me, that in the northern parts of America, comprising regions now inhabited by many herbivorous quadrupeds, the drift snow is often converted into permanent masses of ice. This snow is commonly blown over the edges of steep cliffs, so as to form an inclined

* Humboldt, Fragmens asiatiques, tom. ii. p. 393.

† Reboul, Géol. de la Période quaternaire, who cites Observ. sur la Sibérie, Bibl. Univ., juillet 1832.

talus hundreds of feet high; and, when a thaw commences, torrents rush from the land, and throw down from the top of the cliff alluvial soil and gravel. This new soil soon becomes covered with vegetation, and protects the foundation of snow from the rays of the sun. Water occasionally penetrates into the crevices and pores of the snow; but, as soon as it freezes, it serves the more effectively to consolidate the mass into compact ice. It may sometimes happen that cattle grazing in a valley at the base of such cliffs, on the borders of a river, may be overwhelmed by drift snow and at length enclosed in solid ice, and then transported towards the polar regions. Or a herd of mammoths, returning from their summer pastures in the north, may have been surprised, while crossing a stream, by the sudden congelation of the waters. The missionary Huc relates, in his Travels in Tibet in 1846, that, after many of his party had been frozen to death, the survivors pitched their tents on the banks of the Mouroui-Ousson (which lower down becomes the famous Blue River), and saw from their encampment 'some black shapeless objects ranged in file across the stream. As they advanced nearer, no change either in form or distinctness was apparent; nor was it till they were quite close, that they recognised in them a troop of the wild oxen, called Yak by the Tibetans.* There were more than fifty of them encrusted in the ice. No doubt they had tried to swim across at the moment of congelation, and had been unable to disengage themselves. Their beautiful heads, surmounted by huge horns, were still above the surface, but their bodies were held fast in the ice, which was so transparent that the position of the imprudent beasts was easily distinguishable; they looked as if still swimming, but the eagles and ravens had pecked out their eyes.' †

Considering all the facts above enumerated, it seems reasonable to imagine that a large region in Central Asia, including, perhaps, the southern half of Siberia, enjoyed, at no very remote period in the earth's history, a climate

* Conjectured to be the wild stock of Bos grunniens.

† Recollections of a Journey through Tartary, Tibet, and China (ch. xv. p. 234), by M. Huc. Longman, 1852.

sufficiently mild to afford food for numerous herds of elephants and rhinoceroses, *of species distinct from those now living.* It has often been taken for granted that herbivorous animals, of large size, require a very luxuriant vegetation for their support; but this opinion is, according to Mr. Darwin, completely erroneous:—'It has been derived,' he says, 'from our acquaintance with India and the Indian islands, where the mind has been accustomed to associate troops of elephants with noble forests and impenetrable jungles. But the southern parts of Africa, from the tropic of Capricorn to the Cape of Good Hope, although sterile and desert, are remarkable for the number and great bulk of their indigenous quadrupeds. We there meet with an elephant, five species of rhinoceros, a hippopotamus, a giraffe, the *Bos Caffer*, the elan, two zebras, the quagga, two gnus, and several antelopes. Nor must we suppose that, while the species are numerous, the individuals of each kind are few. Dr. Andrew Smith saw, in one day's march, in lat. 24° S., without wandering to any great distance on either side, about 150 rhinoceroses, with several herds of giraffes, and his party had killed, on the previous night, eight hippopotamuses. Yet the country which they inhabited was thinly covered with grass and bushes about four feet high, and still more thinly with mimosa-trees, so that the waggons of the travellers were not prevented from proceeding in a nearly direct line.'*

In order to explain how so many animals can find support in this region, it is suggested that the underwood, of which their food chiefly consists, may contain much nutriment in a small bulk, and also that the vegetation has a rapid growth; for no sooner is a part consumed, than its place, says Dr. Smith, is supplied by a fresh stock. Nevertheless, after making every allowance for this successive production and consumption, it is clear, from the facts above cited, that the quantity of food required by the larger herbivora is much less than we have usually imagined. Mr. Darwin conceives that the amount of vegetation supported at any one time by Great Britain may exceed, in a tenfold ratio, the quantity existing

* Darwin, Journal of Travels in S. America, &c., 1832–1836, in Voyage of H.M.S. Beagle, p. 98. 2nd ed., London, 1845, p. 86.

on an equal area in the interior parts of Southern Africa. It is remarked, moreover, in illustration of the small connection discoverable between abundance of food and the magnitude of indigenous mammalia, that while in the desert part of Southern Africa there are so many huge animals, there is not, in Brazil, where the splendour and exuberance of the vegetation are unrivalled, a single wild quadruped of the largest size.

It would doubtless be impossible for herds of mammoths and rhinoceroses to subsist, at present, throughout the year, even in the southern part of Siberia, covered as it is with snow during winter; but there is no difficulty in supposing a vegetation capable of nourishing these great quadrupeds to have once flourished between the latitudes 40° and 65° N.

Climate of European Drift and Cave Deposits.—We may now ask, With what European deposits does the frozen mud of Siberia containing the remains of the mammoth in so fresh a state correspond geologically? Their superficial distribution, and the species of mammalia, as well as the fact that the shells which Middendorf and others observed in them are of living species, seem to connect them chronologically with that palæolithic drift in which flint implements have been detected in England, France, and Italy. The temperature which prevailed in the valleys of the Thames, Somme, and Seine at the era in question, was, according to Mr. Prestwich, 20° Fahrenheit colder than now, or such as would now belong to a country from 10° to 15° of latitude more to the north.* This estimate is founded on a careful analysis of the land and fresh-water shells which accompany the remains of the mammoth and its associates in the palæolithic alluvium. If we confine our attention to those terrestrial shells which are most commonly buried in the same gravel and sand as the *Elephas primigenius* and *Rhinoceros tichorhinus*, we find them to amount to no less than 48 species in the valley of the Thames and its neighbourhood. All but two of these still survive in Britain; these two, *Helix incarnata* and *Helix ruderata*, still inhabit the continent of Europe, and have a great range from north to south. The

* Prestwich, Phil. Trans., 1864, part 2, p. 89.

associated fresh-water shells, more than twenty in number, are also British species; but as they occur, with two or three exceptions, as far north as Finland, their presence is not opposed to the hypothesis of a cold climate, especially as the *Limnææ* are capable of being frozen up, and then reviving again when the river-ice melts. At Fisherton, near Salisbury, one of the rude flint implements of the earliest stone age was found in drift containing the mammoth and Siberian rhinoceros, together with the Greenland lemming and a *Spermophilus*, another northern form of rodent allied to the marmot, besides the tiger, hyæna, horse, and other extinct and living species; the whole assemblage being confirmatory of the opinion, that the men of the early stone period had often to contend with a climate more severe than that now prevailing in the same parts of Europe.* The late Edward Forbes compared the condition of Britain and the neighbouring parts of the continent, during the period next preceding the historical, to the 'barren grounds' of Boreal America, including the Canadas, Labrador, Rupert's Land, and the countries northwards where the reindeer, musk-ox, wolf, arctic fox, and white bear now live.† But we find in some parts of the drift evidence of a conflicting character, such as may suggest the idea of the occasional intercalation of more genial seasons of sufficient duration to allow of the migration and temporary settlement of species coming from another and more southern province of mammalia, so that their remains were buried in river gravels at the same level as the bones of animals and shells of a more northern climate. If we allow a vast lapse of ages for the accumulation of the drift, we may take for granted that there must have been such changes in climate, owing chiefly to geographical conditions to be explained in the twelfth chapter, and perhaps sometimes modified by astronomical causes, which will be treated of in the thirteenth chapter. Bones of the hippopotamus, of a species closely allied to that now inhabiting the Nile, are often accompanied in the valley of the Thames and elsewhere

* Ant. of Man, 3rd edit., Appendix, p. 5.

† See an admirable essay by E. Forbes, in the Memoirs of Geol. Survey of Great Brit., vol. i. p. 336. 1846.

by a species of bivalve shell, *Cyrena* (*Corbicula*) *fluminalis*, now living in the Nile and ranging through a great part of Asia as far as Tibet, but quite extinct in the rivers of Europe. Imbedded in the same alluvium with this shell, we find at Grays in Essex, *Unio littoralis*, a mussel no longer British, but abounding in France in rivers more southern than the Thames. The *Hydrobia marginata* is also a shell sometimes met with in the drift, a species now inhabiting more southern latitudes in Europe. The kind of elephant and rhinoceros accompanying the Cyrena at Grays (*E. antiquus* and *R. megarhinus*) are not the same as the mammoth and rhinoceros which occur with their flesh in the ice and frozen mud of Siberia, or in those assemblages of mammalia which have an arctic character in the drift of England, France, and Germany. Some zoologists conjecture that the fossil species of hippopotamus was fitted for a cold climate, but it seems more probable that when the temperature of the river-water was congenial to the Cyrena above mentioned, it was also suited to the hippopotamus.

Glacial Epoch.—The next step of our retrospect carries us back to what has been called the Glacial Epoch, which, though for the most part anterior to the valley-drifts and cave deposits of the palæolithic age above mentioned, was still so closely connected with that period that we cannot easily draw a line of demarcation between them. The dispersion of large angular fragments of rock, called erratics, over the northern parts of Europe and North America, far from the nearest parent rocks from which they could have been derived, had long presented a difficult enigma to geologists before it began to be suspected that they might have been transported by ice, either on land or by floating bergs, at a period when large parts of the present continents were submerged beneath the sea.

These blocks are observed to extend in Europe as far south as lat. 50°, and still farther in America, or to lat. 40°. It was remarked that some of them were polished, and striated on one or more of their sides in a manner strictly analogous to stones imbedded in the moraines of existing glaciers in the Alps. In many areas covered with them both in America

and Europe, the underlying solid rocks were seen to be marked by similar scratches and rectilinear furrows, their direction usually coinciding with the course which the erratics themselves had taken. As both the smoothing and striation of the transported fragments and the surfaces of the rocks *in situ* were identical in character with those recently produced by existing glaciers, it was at length admitted (but not till after the point had been controverted for a quarter of a century, and in direct opposition to the opinion of the earlier geologists) that the climate which preceded the historical was not only colder as far south as lat. 50° in Europe, and even to 46° in the Alps, but was marked by an intensity of cold quite unequalled at present in corresponding latitudes, whether in the northern or southern hemisphere.

Some marine shells of living arctic species, and which no longer frequent the seas of temperate latitudes, were found in the glacial drift of Scotland and North America; so that evidence derived from the organic as well as from the inorganic world conspired to establish the former prevalence of a climate now proper to polar latitudes throughout a great part of Europe.

By means of these drifts, and others containing assemblages of marine shells more or less northern in character, great oscillations in the level of the land since the commencement of the Glacial epoch were proved to have taken place. The change of level in Scotland, as demonstrated by this kind of proof, amounts to more than 500 feet, in some parts of England, as in Cheshire, to 1,300, and in North Wales to 1,400 feet; these movements having all occurred in Post-Tertiary times, or within the period of the living testacea. But Professor Ramsay infers, from the position of the stratified drifts of the Glacial period in North Wales, that the full extent of the vertical movement which brought about first the submergence and then the re-emergence of the land exceeded 2,000 feet.

Inter-Glacial Periods.—Without entering in this place into the proofs of two continental periods in Britain during the Glacial epoch, separated from each other by a long interval of submergence, during which Great Britain and

Ireland were in the state of an archipelago of small islands, it may be affirmed that the excessive cold lasted for a long series of ages, although not always with the same intensity. As illustrative of the fact of the cold having been intermitted or sometimes mitigated for a season, may be mentioned what the late Hugh Miller called 'striated pavements.' These consist of horizontal surfaces of boulder clay, in which the imbedded boulders are seen to have been subjected to a process of abrasion similar to that which the solid rock below had previously undergone. In such instances large stones or blocks fixed in the clay have not only their original and independent striæ, but have subsequently suffered a new striation which is parallel and persistent across them all. These appearances have been observed on the shores of the Firth of Forth, below Edinburgh, and in other places, both on the east and west coasts of Scotland, and on the shores of the Solway in England. Some examples of this second striation may have been due to the friction of icebergs on the bed of the sea during a period of submergence; others to a second advance of land glaciers over moraines of older date.*

M. Morlot and others have adduced abundant evidence of two glacial periods in the Alps, during the first of which the glaciers attained colossal dimensions, filling the great valley of Switzerland with ice, which reached from the Alps to the Jura, while on the southern side of the great chain other contemporaneous glaciers invaded the plains of the Po, where they have left moraines of truly gigantic dimensions. After these huge glaciers had retreated for a time, they advanced again, and though not on so large a scale, they still vastly exceeded in size the largest Swiss glaciers of our day. The interval of milder weather, marked by the decrease of snow and ice in the Alps, has been called by Prof. Heer the Inter-Glacial period, which must have been of considerable duration, for it gave time for the accumulation of dense beds of lignite, like those at Dürnten, and other localities near Zürich. During this intercalated

* A. Geikie, Phenomena of Glacial Drift of Scotland, p. 66, who cites Messrs. C. Maclaren, Hugh Miller, Milne-Holme, and Smith of Jordan-hill.

series of warmer seasons the climate is supposed by Heer to have closely resembled that now experienced in Switzerland. He infers this from the fossil flora of the lignite, especially from the occurrence of cones of the Scotch and spruce firs, and the leaves of the oak and yew, all of living species, as well as from the seeds of certain marsh plants. The insects also, and the fresh-water shells, tell the same tale. Among the mammalia occurring in the lignite-bearing shales of Dürnten are an elephant (*E. antiquus*), an extinct species of bear (*Ursus spelœus*), and a rhinoceros different from *R. tichorhinus*. That the formation of the shale and lignite containing the above-mentioned remains was both preceded and followed by periods of greater cold is shown on the one hand by the polished and striated rock surfaces on which the shale and lignite rest, and on the other by the large size of the erratic blocks which are superimposed upon them.*

In England the lignite, or Forest Bed as it is called, of Cromer, on the Norfolk coast, presents a singular analogy to that to Dürnten above described. It contains in like manner the cones of the spruce and the Scotch fir, and the seeds and leaves of marsh plants, and some shells and mammalia in common with the Swiss deposit. It was also preceded and followed by a period of greater cold. The antecedence of a colder climate is proved by the arctic character of a large proportion of the shells of living species included in the marine strata of Chillesford, near Ipswich, in lat. 52° N., which, according to the observations of Messrs. Prestwich and Searles Wood, are more ancient than the forest or lignite bed. On the other hand, that the Forest Bed of Cromer was followed by an era of severe cold, is shown by the fact that it underlies the great mass of glacial drift, which is in part unstratified, and contains boulders and angular blocks transported from great distances, and some of them exhibiting polished and striated surfaces.†

We are by no means sufficiently advanced in our interpretation of the monuments of the Glacial epoch, and of the long succession of events which mark its history, to be able to affirm that the inter-glacial periods of Dürnten and

* Heer, Urwelt der Schweiz, p. 532. † Antiquity of Man, pp. 212–218.

Cromer, above mentioned, were contemporaneous; but they both of them alike demonstrate that there were oscillations of temperature in the course of that long epoch of cold. There were also great changes, as before stated, in the form of the earth's crust, many movements of upheaval and subsidence, and many conversions of sea into land, and land into sea, during the Glacial epoch. We are in danger of underrating the quantity of time during which the cold prevailed; because, in proportion as the ice increases in thickness, it cancels all marks of antecedent glaciation. The grinding action of the great ice-sheet which now envelopes Greenland illustrates this process. Were that ice to melt, it would require as much skill to detect the evidence of the moraines and erratics of an older time as in the case of a palimpsest to recover the work of the original author, which had been purposely washed out to make room for the new manuscript.

From the foregoing observations, the reader will learn that the prevalence of a colder climate at the close of the Tertiary, and in the early part of the Post-Tertiary periods, has been inferred from two perfectly independent sources of evidence, the first of which may be called inorganic, such as erratic blocks, moraines, and the polishing and striation of rocks; and the second, organic, such as the arctic character of the shells found in the drift of temperate regions. But another or third proof was also pointed out by the late Edward Forbes, as derivable from the present geographical distribution of animals and plants in mountainous regions, especially in high latitudes, in Europe and North America. After the refrigeration of the northern hemisphere had lasted for thousands of years, an arctic fauna and flora must have inhabited the lower lands of temperate latitudes, at a time when the more elevated parts of the same country were buried under permanent snow and ice. On the return of a warmer climate, when the excess of snow was gradually reduced, the arctic species of plants, insects, birds, and mammalia, would ascend to the higher parts of each continent, while the plains would be invaded by species migrating from the south. Hence an arctic fauna and flora, which

once extended from polar latitudes far to the south, ranging continuously over what are now the temperate regions of America, Europe, and Asia, became restricted to the summits of the highest chains, such as the Alps or the mountains of Scotland, Scandinavia, and New Hampshire in the United States. The identity of the species now found in isolated patches at or near the tops of so many widely separated mountains would have been inexplicable, had not the geologist discovered that about the close of the Tertiary era there was a glacial epoch instead of that warm temperature formerly assigned to times preceding the historical.*

British Pliocene strata, showing transition from warmer to colder climate.—When we pass beyond the ages when a colder temperature prevailed, and, receding a step farther into the past, examine the fossils of the British Pliocene strata, we find in the earliest or lowest members of them very interesting proofs of a climate warmer than that now prevailing in England, and more resembling that of the Mediterranean. As we ascend in the series, the shells of successive groups of strata, provincially called crag in Norfolk and Suffolk, are seen to consist less and less of southern species, while the number of northern forms is always augmenting, until in the uppermost or newest groups, in which almost all the shells are of living species, the fauna is very arctic in character, and that even in the 52nd and 54th degree of North latitude.†

Pliocene strata of Italy.—The Pliocene strata of Italy, commonly called sub-Apennine, point in like manner to a warm climate. Such, for example, of the fossil shells of Sienna, Parma, and Asti as are of species now inhabiting the Mediterranean and the Indian Ocean, correspond in size with individuals taken from the warmer of the two seas, those now surviving in the Mediterranean appearing to be stunted in their growth, as if deprived of the favourable conditions which the Pliocene period afforded them in Italy.‡

* Edward Forbes' Memoirs of Geol. Survey, vol. i. p. 399. 1846.

† See above, p. 195; also Elements of Geol., pp. 198, 204, edit. of 1865; and Student's Elements, 1871, p. 169.

‡ Professors Guidotti of Parma, and Bonelli of Turin, pointed out to me, in 1828, many examples in confirmation of this point.

It may also be observed, that the extinct species of the sub-Apennine fauna belong, in great part, to forms which are now most largely developed in equatorial regions, as, for example, the genera Cancellaria, Cassidaria, Pleurotoma, and Cypræa.

Warm climate of Upper Miocene Period.—The next step in our retrospective survey carries us to the monuments of the Upper Miocene period. In the marine formations of this era a third or more of the testacea belong to living species, not a few of which are now inhabitants of more southern latitudes, and of the associated fossil species unknown as living some belong to genera now characteristic of more southern climates. Although in Great Britain Upper Miocene strata are entirely wanting, they occur in Belgium and North Germany, where they contain shells of the genera Conus, Cancellaria, and Oliva—forms all of them foreign to our seas as well as to our British Pliocene deposits, and proper to and indicative of a higher temperature.

The French strata of the same age, called the Faluns of the Loire, point to similar inferences, and, like the contemporaneous beds of the Vienna basin, contain some fossil shells of species now living in Senegal or off the western coast of Africa. The Upper Miocene flora and fauna of the whole of Central Europe afford unmistakable evidence of a climate approaching that now only experienced in sub-tropical regions. In one of the newest deposits of this Upper Miocene formation, Professor Heer has detected, at Œninghen, in Switzerland, the leaves, fruits, and sometimes flowers of about 500 species of plants, in which we find a near resemblance to the flora of the Carolinas and other Southern States of the American Union. After selecting 483 of these species as capable of comparison, specifically or generically, with plants now living, he finds that 131 are such as might be referred to the temperate zone, 266 to a sub-tropical, and 85 to a tropical latitude. In the present state of the globe, the island of Madeira presents the nearest approach to such a flora. The proportion of arborescent as compared to the herbaceous plants is very great, and among the former the predominance of evergreens implies an absence of severe

winter cold. A rich insect fauna, such as belongs to a warm climate, is also attested by the great number of the species of those genera which are most easily preservable in a fossil state. The reptiles which play so insignificant a part in the Pliocene fauna of Central and Northern Europe form a more conspicuous feature in these Miocene formations. At Œninghen there are two tortoises and three species of salamanders, one of them more gigantic in size than the living species of Japan. Bones of the monkey tribe are also met with in Upper Miocene strata near the foot of the Pyrenees in France. Among them is a gibbon, or long-armed ape, equal to man in stature, and the femur of a large species of this family has been detected by Dr. Kaup in strata of the same age at Eppelsheim, near Darmstadt, in a latitude which corresponds to the southern part of Cornwall.* In Greece also, near Athens, the remains of Upper Miocene quadrumana have been met with, confirming the inferences as to the warm temperature of Europe previously drawn by naturalists from the fossils, shells, and corals of Touraine, Bordeaux, and Vienna.

Fossils of the Siwâlik Hills.—It is a matter of no small interest to have learnt that when the climate of Europe was sub-tropical, a still greater heat prevailed nearer the equator. Our best information on this subject is afforded by the investigations of Dr. Falconer and Sir Proby Cautley, who collected, in 1837, a large number of fossil remains from the Siwâlik hills, which skirt the southern base of the Himalaya to the west of the river Jumna. Here the abundance and variety of the fossil mammalia is prodigious, there being no less than seven species of proboscidians of the genera mastodon and elephant. With these a huge extinct four-horned ruminant, called Sivatherium, was found, as well as a camel, a hippopotamus, a hyena, and more than one species of monkey. The associated reptiles also bear witness to a temperature higher than that of any European strata of the same date, for, besides some extinct saurians larger than any now existing, we find among them the living crocodile of the Ganges, *C. biporcatus*, and the living gavial of the same river,

* Owen, Geol. Trans., 1862, and Geologist, 1862, p. 247.

besides a colossal extinct tortoise, of which the shell was no less than eight feet in diameter.

Upper Miocene strata of the West Indies.—If again we turn to the Upper Miocene formations of the West Indies, those, for example, of Antigua, San Domingo, and Jamaica, we discover in them species of corals similar to those found in beds of the same age at Vienna, Bordeaux, and Turin, and some of which, as Dr. Duncan has shown (1863), have a near affinity to species now living in the Pacific (South Sea), Indian Ocean, and Red Sea. They lead irresistibly to the opinion that there was a much greater analogy in those ages than there is now between the temperature of the West Indies in lat. 18° N. and that of Europe in lat. 48° N.*

Dr. Duncan concludes therefore, not only that there was no Isthmus of Panama, but also that there was no great barrier of land or Atlantic continent separating the Miocene seas of Europe from the contemporaneous seas of the West Indies. Already in 1850 Mr. John Carrick Moore had pointed out that certain Tertiary shells of San Domingo exhibited affinities to the Miocene shells of Europe,† and that, although such of the San Domingo species as agreed with the living were chiefly Atlantic forms, there were some so closely allied to the existing Pacific fauna as to lead him to infer that there had been a channel in Miocene times through what is now the Isthmus of Panama, by which the mollusca could have migrated from one ocean to the other. Such an hypothesis, he observes, will be the more readily accepted when we consider that the summit-level of the Panama Railway above the sea is only 250 feet, and that the isthmus nowhere attains an elevation exceeding 1,000 feet, which is not half the height to which the marine Miocene strata of San Domingo have been uplifted since their deposition.

Mr. Etheridge has inferred from these and other researches that the separation from the Pacific dates from the commencement of the upheaval of the Miocene deposits of the Isthmus of Panama, which upheaval probably was not completed until the Pliocene age.

* Duncan, West Indian Corals, Quart. Geol. Journal, p. 455, vol. xix. 1863.

† Quart. Geol. Journ., 1850, vol. vi. p. 43.

Lower Miocene strata.—By referring to our table at page 135, the reader will see that the Lower Miocene strata come next in order as we recede from the more modern formations to those of higher antiquity. They contain scarcely any living species of shells or plants, yet so many of their fossil remains are common to them and the Upper Miocene formation, that this fact alone would lead us to expect that they would afford indications of a warm climate. Such an anticipation is more than confirmed, both by negative and positive evidence; for, in the first place, nearly all the genera of plants which in the Œninghen beds were mentioned as characteristic of temperate latitudes, are wanting in the Lower Miocene, while the tropical forms are more numerous. Among these last are palms of the genus Phœnicites, closely allied to the date-palm. About 80 other plants are enumerated by Heer, all of which would be cut off by such a winter as now prevails in Central and Southern Europe. Ligneous plants constitute two-thirds of the flora, and the preponderance of evergreens exceeds even that observed in the Upper Miocene strata of Œninghen. There are also more reptiles in these older beds and some of considerable size. Among them are no less than three crocodiles and fifteen land and fresh-water tortoises.*

Miocene fossil flora of Arctic latitudes.—The Lower Miocene flora has been traced from Italy northwards to Devonshire, and even to Iceland. In these high latitudes, however, the tropical and sub-tropical genera disappear, though the vine, tulip-tree, and some other forms indicate a temperature 15° or 20° Fahr. warmer than that now belonging to the same countries.†

We find in certain beds of lignite or surturbrand in Iceland, recently examined by Professor Heer, an assemblage of fossil plants resembling in many respects that of Œninghen, before mentioned. Though not of so sub-tropical a character, they employ a warmth so much exceeding that now enjoyed in Iceland as did the temperature of the Upper Miocene flora

* Heer, Urwelt der Schweiz, p. 401.

† Heer and Gaudin, Climat du Pays tertiaire, pp. 174, 207.

of Central Europe surpass that of the vegetation now proper to the same region.*

The extent to which the Miocene flora flourished within the Arctic circle, even as far towards the pole as our exploring expeditions have penetrated, has been clearly pointed out by Professor Heer, in an important treatise on the fossil flora of the Arctic regions.† In the numerous plates which illustrate this work, we see figures of more than sixty species of North Greenland fossil plants found opposite Disco Island, lat. 70° N. Among them are several species of Sequoia (*Wellingtonia*), with their male catkins and cones, agreeing specifically with Lower Miocene plants of Switzerland, Germany, or England. There are also seven other conifers, four poplars, two willows, three species of beech, four of oak (some of which have leaves half a foot long), a plane-tree, a walnut, a plum or prunus, a buckthorn, an andromeda, a daphnogene with large leathery leaves, and several other evergreens, some of extinct genera. The large-leaved trees imply, according to Heer, a high summer temperature, while the evergreens exclude the idea of a very cold winter. That these and other fossil plants from arctic localities really lived on the spot, and were not drifted thither by marine currents, is proved by the quantity of leaves pressed together, and in some cases associated with fruits, also by the marsh plants which accompany them, and by the upright trees with roots which were seen by Captain Inglefield and by Rink.

Still farther north in Spitzbergen, in lat. 78° 56′ N., no less than 95 species of plants are described by Heer, many of them agreeing specifically with North Greenland fossils. In this flora we observe Taxodium of two species, a hazel, poplar, alder, beech, plane-tree, lime (*Tilia*), and a potamogeton, which last indicates a fresh-water formation, accumulated on the spot. Such a vigorous growth of fossil trees, in a country within 12° of the pole, where there are now scarcely

* Heer and Gaudin, Climat du Pays tertiaire, p. 178.

† Heer, Flora Fossilis Arctica, with 40 illustrative plates, containing figures of fossil plants, collected by M. Nordenskiold, and Captain Sir L. McClintock, Sir R. Maclure, Colomb, Inglefield, and others.

any shrubs except a dwarf willow, and where there are only a few herbaceous and cryptogamous plants, most of the surface being covered with snow and ice, is truly remarkable. When the fossils are compared with the Miocene species of Central Europe and Italy, many of them are found to be the same, and it is clear that the climate was not only much warmer than now, but the temperature of Europe and the Arctic circle was much less contrasted ; nevertheless, the flora of Spitzbergen was by no means so sub-tropical at the era alluded to as was that of Switzerland, Germany, and Devonshire, for in the Lower Miocene period the difference of latitude made itself felt as now, although in a less degree. Professor Heer infers, with great probability, that pines, alders, poplars, willows, and other hardy genera reached the pole itself in Miocene times, if there was land there, because they range at present from 4 to 10 degrees farther north than the Taxodium, beech, plane, and lime, which accompany them in a fossil state in the same formation at Spitzbergen. Some of the last-mentioned genera are in a higher latitude in Spitzbergen, by 8, 17, and 23 degrees, than the living representatives of the same genera. We cannot hesitate, therefore, to conclude that in Miocene times, when this vegetation flourished in Spitzbergen, North Greenland, and on the Mackenzie river, as well as Banks Land, and other circumpolar countries, there was no snow in the arctic regions, except on the summit of high mountains, and even there perhaps not lasting throughout the year.

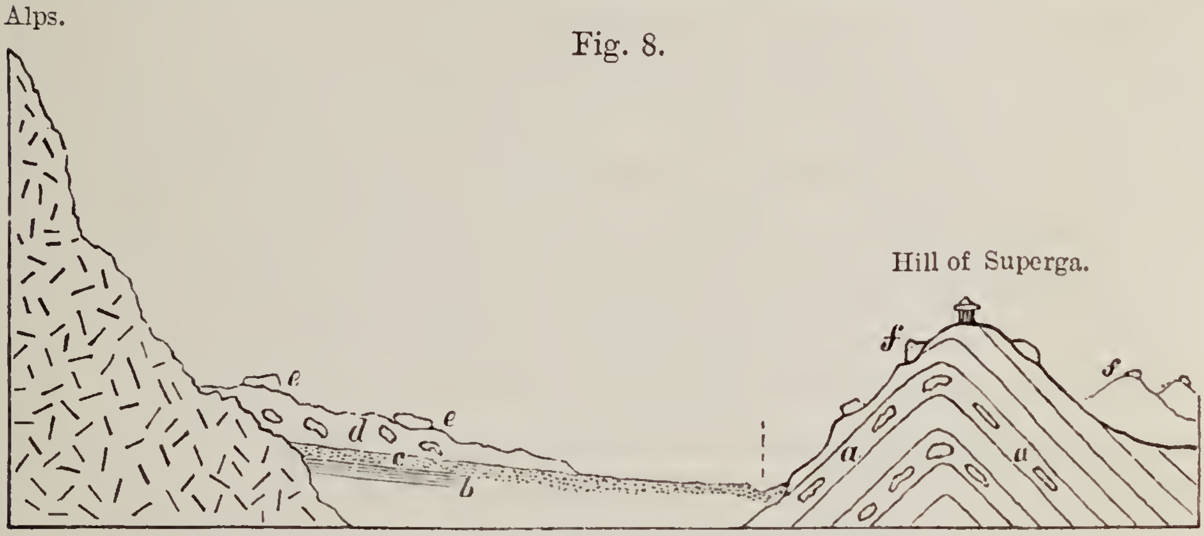
Ice-action in the Miocene Period.—If it be asked whether in the entire Miocene series there are no indications of intercalated spells of colder climate, like the glacial episode before mentioned as intervening between the older Pliocene and the modern eras, I may reply that there are none which can at present be established on organic evidence; but our geological records are far too fragmentary to entitle us positively to assume that, in the course of so vast a succession of ages, there were no oscillations of temperature analogous to those which certainly occurred between the close of the Newer Pliocene period and our own time. Professor Ramsay, who has so successfully devoted much time

and thought to the search for indications of glacial action in remote eras, reminds us that a geologist must expect to encounter great difficulties in such investigations. If, at some future era, when large portions of the existing continents shall have been submerged and overspread with marine strata, and other parts of them destroyed by denudation, we should have the task assigned to us of detecting those spots where ancient land-surfaces had escaped destruction, or where erratic blocks and moraines of glaciers were extant, we might well despair of success. It rarely happens that we have opportunities of examining terrestrial surfaces of high antiquity, and when visible, their extent is always very limited. In the majority of cases they will consist of rocks incapable of receiving and preserving a glacial polish and striation. The least evanescent of the proofs of ice-action, which our era is likely to transmit to future ages, are, unquestionably, those large angular erratics which have been carried to great distances from their parent rocks; and wherever such masses occur in older strata they deserve particular attention. I shall proceed, therefore, to describe a formation of Miocene date, which I have myself examined, in which the position and size of the included blocks is such as to make it impossible at present to account for their transportation by any other cause than the buoyant power of ice.

The marine deposits alluded to consist of strata of sandstone and conglomerate, and constitute a member of the Miocene formation of the Collina of Turin, a chain of hills in the suburbs of the capital of Piedmont, on the brow of which stands the church of the Superga. These strata have long been celebrated for containing a plentiful store of fossil shells of the same species as those of the faluns of Touraine, Bordeaux, and Vienna. The annexed diagram will give the reader some idea of the position of this conglomerate (*a*), which is highly inclined and conformable to the other strata which dip on each side to the north-west and south-east from the axis of the chain. I examined the district in 1857, in company with Signor Gastaldi, one of the ablest of the Italian geologists, and one well versed in glacial phenomena.

On this occasion I satisfied myself that Signor Gastaldi was right in supposing that the large blocks *f f*, lying on the surface of the hills, had been washed out of the beds *a a*, by the same action which has hollowed out the valleys.* In other words, they have not been brought from a distance, as was once supposed, during the more modern or Post-Pliocene Glacial period, like the erratics *e*, which rest on the moraine *d*, but have been washed out of the Miocene beds in the immediate neighbourhood, viz., the conglomerate *a*. This last

Fig. 8.



Section from the Alps to the Hill of the Superga, showing the position of the Miocene erratic blocks.

a. Conglomerates of Miocene age with large blocks.
b. Marine sub-Apennine or Pliocene strata.
c. Diluvium or ancient alluvium of various ages, some of it below the moraine *d*.
d. Moraine of Ivrea of the Glacial period, with erratic blocks.
c. Erratic blocks lying on the moraine *d*.
f. Miocene blocks washed out of the conglomerate *a*, and scattered over the hills of the Superga chain.
N.B.—The distance from the Alps to the Superga is about thirty miles.

is part of a regular series of strata, composed chiefly of sand of various degrees of coarseness, and of gravel, in which are rolled pebbles of greenstone (or diorite), limestone, porphyry, and some other rocks. Among them we occasionally meet with fragments of serpentine and greenstone, of enormous size, one of which I ascertained by measurement to be 14 feet in its longest diameter. Signor Gastaldi has seen another in the same formation, 26 feet long; they are angular,

* Gastaldi, Sui Conglomerati Mioceni del Piemonte. 1861.

and several of those which I saw, exhibited some faint striæ and had one of their sides polished, in a manner much resembling that produced by glacial action. The whole thickness of the beds through which these blocks are dispersed varies from 100 to 150 feet. As yet they have yielded no organic remains, but they are covered by strata containing shells of the Upper Miocene formation, and they rest on Lower Miocene strata for the most part of fresh-water origin. The fauna and flora, both of the overlying and underlying rocks, have the same sub-tropical character as those of Miocene date in Switzerland and in Central Europe generally. Hence the hypothesis of the transport of such huge blocks by ice-action has naturally been resorted to most unwillingly, but in the present state of our knowledge it is the only one which appears tenable. The beds of sandstone alternating with those in which the blocks are enveloped exhibit no signs of having been tumultuously accumulated as by a flood. The erratics seem rather to have fallen quietly into their places. The nearest spots where any similar serpentine and greenstone occur are about twenty miles to the westward, but there has been so much subsidence of the country during the Miocene period, so much subsequent deposition of overlying miocene, pliocene, and alluvial deposits, and such changes in physical geography, that we cannot decide with any certainty as to the proximity or distance of the spots from which the blocks may have come. The absence of organic remains may possibly imply a sea chilled by floating ice, or by a cold current from the north; but such an hypothesis is not very satisfactory, because the thickness attained by the conglomerate in some parts of Piedmont is very great, far exceeding that seen in the vicinity of Turin. We must conclude, therefore, that its accumulation occupied a great lapse of time, and if so, it is difficult to understand why there are no organic remains in it: for although the temporary influx of a cold current might well be supposed to annihilate a fauna fitted for a warmer sea, yet the long continuance of such a current would naturally fit the region for species such as thrive in the seas of colder latitudes. Perhaps a lofty mountain, with a glacier reaching the sea, would be the least objectionable

hypothesis, since in Patagonia there is a glacier descending from the Andes in Eyre Sound, in the latitude of Paris, and another in the neighbouring Gulf of Penas, lat. 46° 50′ (or the latitude of the Bernese Alps), both of which convey large erratic blocks to the Pacific, into which they are floated by numerous icebergs.

Eocene Fauna and Flora.—In the flora of the upper members of this great series, we find in the neighbourhood of Paris and in the Isle of Wight, some plants which, like the palmetto, attest a warmer temperature. Among the accompanying reptiles, there are many crocodiles and tortoises, such as we now only meet with in more southern regions. In the Middle Eocene, as in the calcaire grossier, for example, near Paris, the marine testaceous fauna is richer and more varied than that now proper to seas so far north. The flora of the same division of the Tertiary period, as, for example, that of Alum Bay in the Isle of Wight, of Monte Bolca in the North of Italy, or that of Aix en Provence in the South of France, comprises species and genera having a great affinity to Lower Miocene forms, but departing farther than do these from the modern European type, and, according to Heer, resembling in many respects plants of the tropical regions of Australia and India.

The nummulitic formation of this era is of world-wide extent, and contains many corals of large size, of genera now common in tropical seas, some of the same fossil species ranging from Sinde in India to the West Indies.

If, lastly, we turn to the Lower Eocene strata, we find in the London clay of the Isle of Sheppey fossil fruits of the cocoa-nut, screw-pine, and custard-apple, reminding us of the hottest parts of the globe; and in the same beds are six species of *Nautilus*, and other genera of shells, such as Conus, Voluta, and Cancellaria, now only met with in warmer seas. The fish also of the same strata, of which 50 species have been described by Agassiz, are declared by him to be characteristic of hotter climates, and among the reptiles are sea-snakes, crocodiles, and several species of turtle.

Supposed signs of ice-action in the Eocene Period.—In a bed of coarse conglomerate of the Eocene period in the Alps,

phenomena in many respects analogous to those of the neighbourhood of Turin present themselves. This conglomerate is a subordinate member of that vast deposit of sandstone and shale which is provincially called 'flysch' and 'nagelflue,' and which, by its position (for it is devoid of organic remains), seems referable to the middle or 'nummulitic' portion of the great Eocene series. The well-known 'Vienna sandstone' is a member of this flysch, which extends for 300 miles at least, east and west, from Vienna to Switzerland, along the northern flanks of the Alps, and is again seen in the south, near Genoa, and in several parts of the Apennines, where it is called by the Italians 'macigno.' Its thickness is very great, amounting to several thousand feet, and occasionally, according to some authorities, to 6,000 feet. It is often finely stratified, and singularly barren of fossil remains, although in a few places it contains fucoids. Here and there, as in the Sihlthal, near the lake of Zürich, and in the Toggenburg in St. Gall, large blocks are enclosed in it, some of them angular and others rounded. These blocks are occasionally of limestone, and contain ammonites and other fossils of the oolitic and liassic formations, as described by Dr. Bachmann.* Blocks also of a red variety of granite of a peculiar composition, not known *in situ* in any part of the Alps, occur in the same conglomerate of the flysch. In several places the blocks are 10 feet long, but at Habkeren, on the north side of the lake of Thun, many are seen of enormous dimensions, one of them being 105 feet in length, 90 in breadth, and 45 in height. They have lost their edges, either by friction or decomposition, but are not polished or striated.

There has been a lively discussion as to whether the largest of the above-mentioned Habkeren blocks came out of the flysch, or were simply erratics of the Glacial period; † but Escher von der Linth, Studer, Rütimeyer, and Bachmann are clearly of opinion that they have been washed out of the coarse conglomerate. The flysch of Bolgen, near

* Bachmann, Petrifakten und erratische Jurablöcke im Flysch des Sihlthals, and Toggenburg.

† Murchison, Structure of Alps, Quart. Geol. Journ., vol. v. 1849.

Sonthofen, also contains foreign blocks of considerable size, and similar masses, as I am informed by Professor Suess, occur in Tertiary strata of the same age in the Carpathians and Apennines, but neither on them nor on any others have any glacial striæ been as yet observed. We have to account not only for the wonderful size of the granitic rocks, varying from 10 to 100 feet in diameter, but for the distance which they have travelled, which seems to be implied by our inability to refer them to any known source. They are distinguishable by their mineral character from all granitic erratics of the true or modern glacial period, such as are strewed over the surface of those districts of Switzerland where there is no outcrop of flysch conglomerate. The hypothesis that these huge masses were transported to their present sites by glaciers or floating ice, has been always objected to on the ground that the Eocene strata of nummulitic age in Switzerland, as well as in other parts of Europe, contain genera of fossil plants and animals characteristic of a warm climate. It has been particularly remarked by M. Desor, that the strata most nearly associated with the flysch in the Alps are rich in echinoderms of the Spatangus family, which have a decidedly tropical aspect. The entire absence of shells, or of organic remains generally, may perhaps be thought to favour a glacial origin for the flysch, but this negative character is too common in strata of every age to be of much value, except in connexion with other proofs of intense cold. Nor must we disguise from ourselves the fact, that in the seas of polar regions where icebergs abound at present there is by no means any dearth of animal life. On the other hand, the regular stratification and even fine lamination of large portions of the flysch cannot be said to be inconsistent with a glacial origin, for on the Norfolk coast we see thinly laminated clays devoid of organic remains forming an integral part of unquestionable glacial deposits.

The great thickness of the flysch, and the fucoids preserved in a few beds of it, lead to the conclusion that it was of marine origin, To imagine icebergs carrying such huge fragments of stone in so southern a latitude, and at a period

immediately preceded and followed by the signs of a warm climate, is one of the most perplexing enigmas which the geologist has yet been called upon to solve. It would perhaps be most in accordance with existing analogies to suppose a mountainous island occupying the site of the Austrian and Swiss Alps from which glaciers descended to the sea. For in the southern part of New Zealand, between latitudes 43° and 44° S. in the southern (formerly called the middle) island, glaciers coming from Mount Cook, the loftiest mountain of a snow-covered chain, reach to within 500 feet of the sea, and the same region is inhabited not only by tree-ferns, but by an Areca palm. These plants of tropical aspect are now seen flourishing in this district, very near to moraines and angular fragments of stone recently brought down by ice from the higher regions. But we shall see (Chap. XVI.) that icebergs, sometimes carrying huge erratic blocks, float at the present time in both hemispheres to parts of the sea hundreds of miles from land, in latitudes nearer the equator than the Swiss Alps: we ought not, therefore, to wonder at the occurrence of erratics in any stratum in the temperate regions of the globe, at periods when the temperature resembled that of our time, nor consider them as by any means implying an intensity of cold equalling that of the so-called Glacial Epoch.

CHAPTER XI.

FORMER VICISSITUDES IN CLIMATE—*continued.*

WARM CLIMATE IMPLIED BY THE FOSSILS OF THE CHALK—CRETACEOUS REPTILES—HOW FAR EXTINCT GENERA AND ORDERS MAY ENABLE US TO INFER THE TEMPERATURE OF ANCIENT CLIMATES—EVIDENCE OF FLOATING ICE IN THE SEA OF THE WHITE CHALK OF ENGLAND—WARM CLIMATE OF THE OOLITIC AND TRIASSIC PERIODS—WIDE RANGE OF THE SAME FAUNA FROM SOUTH TO NORTH—ABUNDANCE AND WIDE RANGE OF REPTILES IMPLIES A GENERAL ABSENCE OF SEVERE COLD—THE NON-EXISTENCE OF CONTEMPORARY MAMMALIA WILL NOT EXPLAIN THE PREDOMINANCE OF REPTILES IN HIGH LATITUDES—PERMIAN FOSSILS—SUPPOSED SIGNS OF ICE-ACTION IN THE PERMIAN PERIOD — UNIFORMITY OF THE FOSSIL FLORA OVER WIDE AREAS—MELVILLE ISLAND COAL-PLANTS—HOW FAR THE ABSENCE OF FLOWERING PLANTS VITIATES OUR INFERENCES AS TO ANCIENT CLIMATES—WHETHER THE ATMOSPHERE WAS SURCHARGED WITH CARBONIC ACID IN THE COAL PERIOD—FOSSIL SHELLS AND CORALS OF THE CARBONIFEROUS STRATA—CLIMATE IMPLIED BY THE REPTILES OR AMPHIBIA OF THE COAL—DEVONIAN PERIOD, AND SUPPOSED SIGNS OF ICE-ACTION OF THAT ERA CONSIDERED—CLIMATE OF THE SILURIAN PERIOD—CONCLUDING REMARKS ON THE CLIMATES OF THE TERTIARY, SECONDARY, AND PRIMARY EPOCHS.

In the last chapter I endeavoured to trace back the history of the changes of climate from modern times to the Eocene period, and we found, that before we had carried back our retrospect as far as the Newer Pliocene deposits, proofs already presented themselves, both organic and inorganic, of a temperature much colder than that now prevailing in European latitudes. Although this Glacial epoch, as it has been called, lasted for thousands, if not hundreds of thousands of years, it was of so modern a geological date as to belong almost exclusively to the time when the mollusca were the same as those now living. The geographical range only of species was different, because an arctic fauna was enabled by aid of the cold to invade the temperate latitudes. An examination of the fossils of the Pliocene, Miocene, and Eocene strata, viewed successively in the order of their

higher antiquity, afforded us evidence of a temperature continually increasing, in proportion as we receded farther from the Glacial epoch. If, in certain localities in or near the Alps, some huge transported fragments of rock, enclosed in miocene and eocene conglomerates, seemed to require the aid of ice to bring them into the sites they now occupy, a local combination of geographical circumstances may perhaps be conceived, which might account for such exceptional cases without requiring a general refrigeration of climate at the times alluded to, or, still more probably, floating icebergs may, as suggested (p. 210) in explanation of the Habkeren erratics in the Alps, have brought large fragments from a great distance without requiring us to suppose a lower temperature than that now prevailing on the earth.

Warm climate implied by the fossils of the Chalk or Upper Cretaceous.—When we pass beyond the gap which divides the Tertiary from the Secondary formations, between which there are very few vertebrate genera and no species of invertebrata in common, we observe in the cretaceous strata signs of a warm climate similar to those previously derived from tertiary plants, shells, corals, and reptiles. Many of the principal members of this cretaceous series have been traced from the 57th degree of latitude in the northern hemisphere to districts which approach within 10 or 12 degrees of the equator, as at Pondicherry, Verdachellum, and Trichinopoly. In these countries deposits occur, which by their ammonites and many other mollusca were recognised by the late Edward Forbes as belonging to beds, some of them corresponding to our English Gault, and others to strata which immediately overlie and underlie that formation.* In these Indian formations are found shells of the genera Cypræa, Oliva, Triton, Pyrula, Nerita, and Voluta, which belong to forms now characterising tropical seas, and some of which only made their first appearance in European latitudes in the uppermost or Maestricht chalk. The geographical birthplace, says Forbes, of these genera seems to have been in the tropics before the Tertiary period, during which last they made a great figure in Europe throughout Eocene and Miocene times,

* See Report on Fossils collected by C. J. Kaye, Esq., and Rev. W. H. Egerton, Quart. Geol. Journ., 1845, vol. i. p. 79.

retreating again southwards in the Newer Pliocene era, when the cold of the approaching Glacial epoch had begun to make itself felt.

The plants of the Upper Cretaceous formation of Europe, so far as they are known, have such an affinity with the Eocene flora as to point in the same direction in regard to the existence of a high temperature. They contain a large number of dicotyledonous angiosperms, whereas the Lower Cretaceous rocks are characterised by the absence of these last, and by a predominance of cycads and of conifers of an araucarian type, and of ferns referred by some botanists to genera which also favour the hypothesis of a warm climate.

In reasoning on the organic remains of the Upper Miocene strata of Central and Southern Europe, we had the advantage of drawing our inferences as to the high temperature of the atmosphere and ocean from shells, one-third of which were of living species, while our conclusions were confirmed by the discovery of contemporaneous genera of plants, insects, and corals, as well as of apes and monkeys. The reptiles also were more numerous, some of them of larger size than are now found in temperate regions. In the Lower Miocene formation, crocodiles, chelonians, and large batrachians, and in the Eocene deposits the same genera of reptiles, together with sea-snakes, bore testimony in like manner to the warm temperature of the seas, lakes, and rivers.

When we pass on to the uppermost member of the Cretaceous series, or the Maestricht chalk, as it is called, we find a similarly marked development of reptile life in regions where nothing analogous is now to be met with. Thus, in latitude 51° N., we encounter in St. Peter's Mount, Maestricht, the aquatic reptile called Mosasaurus, which was twenty-four feet in length. The same genus is largely represented in the American cretaceous rocks, from the various divisions of which Dr. Leidy has obtained more than twenty genera of reptiles, most of them extinct, but some, like the tortoises (*Trionyx* and *Emys*) and the crocodiles, of living types.* Several of the crocodiles of this age,

* Leidy, Cretaceous Reptiles of United States. Smithsonian contribution, 1865.

both in Europe and America, are procœlian, that is to say, they have the anterior portion of each vertebra concave, and the posterior part convex, in which respect they agree anatomically with the existing species, and are contrasted with all the older known genera of Mesozoic age. The reader will observe, on consulting Owen's table of the distribution of reptiles in past geological ages,* that of the five living orders, crocodiles, lizards, tortoises, snakes, and frogs, the two last-mentioned have not yet been traced as far back as the Secondary or Mesozoic periods, but the three first, the Crocodilia, Lacertia, and Chelonia, are met with in full strength in Cretaceous times, where they become associated with no less than three extinct orders, namely, Pterodactyls, Ichthyosaurs, and Plesiosaurs. Respecting the first of these, namely, the flying reptiles, it has been argued, that we have no right to assume that they required a hot climate, because they are so highly organised, and have so near an affinity to birds in structure, that they may have been warm-blooded, and as capable as birds of sustaining great cold. But the same argument will not apply to ichthyosaurs or to plesiosaurs, nor to the numerous chelonians which occur in the different divisions of the Cretaceous period, including the Wealden strata, in which large terrestrial saurians are so conspicuous.

How far extinct orders and genera may indicate temperature.—It has been objected, that in speculating on the habits and physiological constitution of plants and animals of an epoch so distant from our own as the Cretaceous, we enter a region of doubt and uncertainty, because even the Eocene species are distinct from the living ones, while the Cretaceous fossils differ as much from the Eocene as do the latter from living types. Dr. Fleming, therefore, when engaged in a controversy with Dean Conybeare, in 1830, as to the proofs of a hotter climate in the olden time, declared that the reasoning of his opponents was illogical, and their mode of dealing with the subject unfair. 'They were playing,' he said, 'with loaded dice;' for the large number of genera are now

* Owen, Palæontology, p. 321.

in tropical and sub-tropical zones, not because they could not live in colder regions, but simply because the land and sea in those zones are of wider extent, and support in equal areas a greater exuberance and variety of animal and vegetable forms. According, therefore, to the doctrine of chances, the majority of the genera of any past epoch, whether they be extinct or not, will have their nearest living analogues in hot countries. Many of them will be unrepresented in the colder parts of the globe, not because of their unsuitableness to the climate of such regions, but because of the comparative poverty of the fauna and flora of high latitudes. The fact, it is said, that the same genus has often species proper to the torrid, temperate, and frigid zones, is enough to demonstrate that it is on species alone that we can rely in questions of climate.*

The caution here enjoined is by no means to be disregarded, but our scepticism on this head may be carried too far. If three assemblages of existing species were submitted to a good naturalist, one of them coming from arctic, another from temperate, and a third from tropical latitudes, he would be able at once to assign the quarter from which each of the three groups had been obtained, even though he might never have seen any one of the *species* before. He would be guided partly by the presence of certain genera and orders, and partly by the absence or feeble representation of others in each group. It is by reasoning of this kind that we are able to arrive at conclusions respecting the temperature of periods when most of the genera and many even of the orders of plants and animals differ from those now living, and it must be remembered that when we study the modern Tertiary formations, in which a considerable proportion of the species are identical with living ones, we are able to infer from their associates what was the climate of many species and genera of animals and plants long since extinct. By this means, our data of comparison, when we are endeavouring to interpret the monuments of antecedent epochs, are greatly increased, since it is not merely to the living creation that we can appeal.

* Edinburgh New Phil. Jour., 1830.

Evidence of floating ice in the sea of the White Chalk in England.—The homogeneous character of the white chalk or upper portion of the great Cretaceous formation throughout a large part of Europe is now explained by the discovery that it is made up almost exclusively of the remains of the calcareous shells of Foraminifera, while the siliceous portions have been derived chiefly from plants called Diatoms. It was ascertained, when soundings were made for the Electric Telegraph, that calcareous mud of a similar character and origin is now forming over vast areas in the depths of the Atlantic. The general absence from the white chalk of sand, pebbles, drift-wood, and other signs of neighbouring land, is thus accounted for, but the occasional discovery of single and perfectly isolated stones, usually consisting of quartz and green schist, in the south-east of England, has naturally excited much surprise. In what manner could such stones have been carried far out into an open sea, so as to fall to the bottom without any admixture of other foreign matter? I formerly endeavoured to explain this enigma by referring to a fact observed by Mr. Darwin, namely, that stones of considerable size are occasionally entangled in the roots of floating trees, and transported to great distances in mid-ocean. One of them, as big as a man's head, was conveyed in this way for 600 miles to Keeling Island, a small ring of coral in the Indian Ocean. Seaweed also, called Kelp, *Fucus vesiculosus*, when uprooted, frequently bears along with it from shallow water pebbles and earth around which its roots have grown.

But, on reconsidering all the facts now observed, I agree with Mr. Godwin-Austen that there are some cases which we cannot account for without introducing the agency of ice. Thus, for example, in 1857, there was found at Purley, near Croydon, in the body of the white chalk, a group of stones, the largest of which consisted of syenite. This block had been broken up by the workmen before it was examined by any scientific observer, but the largest of the fragments was ascertained to be twelve inches in diameter in two directions, and to weigh upwards of twenty-four pounds. It was surrounded by granitic sand and pebbles of greenstone, and its dimensions rendered

the hypothesis of transportation by drift-timber inadmissible. There was, moreover, a total absence of carbonaceous matter, such as might have been looked for if a waterlogged tree had sunk on the spot. Mr Godwin-Austen, therefore, has suggested that the pebbles and loose sand must have been frozen into coast-ice, and then floated out to sea, and the stones, he observes, mineralogically considered, present just such an assemblage as might now be found on a beach on the coast of Norway in lat. 60° N. As to the degree of cold required for the formation of such coast-ice, it may not, the same author remarks, have exceeded that occasionally experienced in our times on the eastern coast of England, from which ice has lifted and floated away far greater weights.*

Another example of a rounded block, weighing above thirteen pounds, had been previously noticed in the 'chalk with flints,' by Mr. Catt (now Mr. Willett), in a pit near Lewes. Attached to it was *Spondylus lineatus*, with serpulæ and some bryozoa. It had evidently been rolled before transportation, and before the serpulæ had fixed themselves on it. But no large angular blocks have as yet been met with in the white chalk, of such a size as to imply the agency of glaciers and icebergs.

Climate of the Oolitic and Triassic Periods.—When we enquire into the climatal state of the globe in times which preceded the Cretaceous, we find a very general agreement among zoologists and botanists as to the warmth of European latitudes in the Oolitic and Triassic eras. The vegetation of these periods consists chiefly of cycads, conifers, and ferns. Professor Heer remarks, that the tree which is most common in the Upper Trias in Switzerland has a near affinity to a living African species of Zamia,† and M. Adolphe Brongniart had long before expressed his opinion that the plants of the secondary periods favoured the hypothesis of a climate like that of the West Indies. The same genera, and, to some extent, the same species of ammonites and some other shells proper to oolitic strata in Europe, occur also in formations of the same age in India, as, for example, in Scinde and in Cutch, lat. 22° N. In a northerly direction the same formations

* Geol. Quart. Journ., vol. xiv., 1858. † Heer, Urwelt der Schweiz, p. 51.

reach within 13½ degrees of the Pole, as was shown by the fossil specimens brought home by Sir Leopold McClintock. Among these the Rev. Samuel Haughton recognises a species closely allied to the *Ammonites concavus* of the Lower Oolite which was found at Prince Patrick's Island, lat. 77° 10′ N. In Cook's Inlet also, lat. 60° N., several ammonites of jurassic types, if not species, were obtained, and *Belemnites paxillosus*, a British liassic fossil. But what is far more remarkable, remains of a large ichthyosaurus of liassic type were brought from an island in lat. 77° 16′ by Sir Edward Belcher. They have been described and figured by Professor Owen, and as some of the vertebræ were 2½ inches in diameter, the animal must have been of considerable size.* More recently, in 1866, the remains of ichthyosaurians were found by the naturalists of the Swedish expedition, in strata of jurassic age in Spitzbergen in the still more northern latitude of 78° 30′.

Abundance and variety of reptiles implies warm climate.—The reptiles of the Oolite and Lias, and of the still older Trias, are so numerous and diversified in form that the period of the secondary or mesozoic rocks has been called the age of reptiles. The number of marine genera alone of this class exceeds fifty, while that of the fresh-water and terrestrial species, including those of aërial habits, is almost as great as that of the tribes which peopled the sea. Some of these were more highly organised than any animals of the same class now living, as the Belodon, for example, of the Upper Trias, a saurian about the size of the largest living crocodile, but which belonged to the extinct order of Dinosaurians. Hermann von Meyer ascertained, in 1865, that it possessed breathing apertures or spout-holes like the whale, so that we might imagine it to have been capable of sustaining a cold climate were it not associated with many reptiles of lower grade, as well as with shells, corals, and plants which bespeak a high temperature. On the whole, no less than eighty reptiles have been described by Hermann von Meyer, all derived from the Trias of Germany alone. They belong entirely to extinct orders, but all of which, according to

* Last of Arctic Voyages.

Owen,* display affinities more or less decided to living families of the same class, while in the overlying liassic and oolitic groups we find representatives of the crocodilian and chelonian orders which still exist, together with the four extinct orders the Pterosaurs, Ichthyosaurs, Plesiosaurs, and Dinosaurs. These exhibit various grades of organization, and the analogy of the living creation is strongly in favour of their having flourished in a climate in which the heat was considerable during part of the year, and the winter brief and never severe.

Thus, in some of the temperate regions of the southern hemisphere at present, where the winters are long and the summers cool, there is an entire absence of reptile life—in Tierra del Fuego, for example, and in the woody region immediately north of the Straits of Magellan (between latitudes 52° and 56° S.), and in the Falkland Islands. Not even a snake, lizard, or frog, is met with; although in these same countries we find the guanaco (a kind of llama), a deer, the puma, a large species of fox, many small rodentia, and, in the neighbouring sea, the seal, together with the porpoise, whale, and other cetacea.

In the arctic regions, at present, reptiles are small, and sometimes wholly wanting, where birds, large land quadrupeds, and cetacea abound. We meet with bears, wolves, foxes, musk-oxen, and deer, walruses, seals, whales, and narwhals, in regions of ice and snow, where the smallest snakes, efts, and frogs are rarely, if ever, seen.

The power of reptiles to bury themselves in the earth, and to hybernate in a state of torpidity, enables them to exist in extra tropical regions, but not where the winter's cold is excessive or of long duration.

Absence of mammalia does not explain the wide range of reptiles.—In none of the secondary rocks, as before stated, have any mammalia clearly referable to the placental division been found, whether of terrestrial or aquatic genera. Their absence may partly account for the extraordinary number of genera, species, and individuals of the reptile class. For the

* See a table of geological distribution of reptiles in Owen's Palæontology, p. 321, 2nd edit., 1861.

reptiles enjoyed in those periods a monopoly of a large portion of the habitable surface which they are now obliged to share with the more powerful mammalia. In the struggle for existence they had only to compete with marsupials of very diminutive size, and, so far as we know, there were few contemporary birds, so that to a great extent the reptiles performed the functions in the air, on the land, and in the water, which the two highest classes of vertebrata now discharge. But granting that the predominance of reptiles is checked in our days by the important part played by the more highly organised vertebrata, we can by no means attribute the present scarcity of saurians (crocodiles and iguanas), lizards, tortoises, snakes, and the larger batrachians in high latitudes, as contrasted with their abundance in secondary periods, to the progress which the animate world has made in that great interval towards a more highly organised state. All the above-mentioned orders of reptiles are able to maintain their ground at present against the ape, elephant, rhinoceros, tiger, deer, and other mammalia, large and small, in all zones where they are favoured by sufficient heat. If they are absolutely wanting in polar regions it is evidently not the competition of the bears, musk-buffalos, walruses, and whales which sets a limit to their range in that direction, but the power of frost.

There is no area in the globe at present, between the parallels of 40° and 60°, where a climate exists like that which we may suppose to have prevailed when the triassic and oolitic rocks were formed. But perhaps the nearest approach to it may be found in the Galapagos Archipelago (situated nearly 600 miles west of the coast of Peru), which is of volcanic origin and contains ten principal islands, some of them from 3,000 to 4,000 feet high, and one of them, Albemarle Island, 75 miles long. Placed under the equator, the heat is greater than in temperate latitudes, but it is moderated by the surrounding ocean, and by a current of cold water which flows from Patagonia northwards along the west coast of South America. This archipelago has been called the land of reptiles, from the extraordinary number of large tortoises, together with lizards and snakes, which it supports. Among the lizards are two species of a peculiar

genus, called Amblyrhyncus, one of them terrestrial and the other aquatic. The latter is marine, laying its eggs in the seaweed under water; it affords the only living example, with the exception of some sea-snakes, of a reptile proper to the ocean, and it serves to show that the existence of seals and cetacea, which abound in the Pacific, forms no bar to the coexistence of aquatic reptiles in the same region. The number of individual tortoises and other reptiles could not possibly be so great in these islands, were it not for the absence of mammalia, for a single indigenous species of mouse was the only representative of this class when Mr. Darwin visited the archipelago in the Beagle in 1835. Even this rodent seems to have been confined to Chatham Island, and may possibly be a variety of a South American form, introduced by the buccaneers. In James Island a rat belonging to the old-world division, no doubt brought by some ship, had been naturalised. All the islands were uninhabited by man until about 1832, when the first small colony was founded. In the fauna of the Galapagos islands we have therefore a state of things very analogous to that of the secondary periods before alluded to.

The rich marine fauna of the St. Cassian beds in the Austrian Alps, and of the district of d'Esino in Lombardy, so well illustrated by Stoppani, affords evidence, through its gigantic Ammonites and Orthocerata, and by the large size of the Gasteropoda and Lamellibranchiata, that in the east of Europe the seas enjoyed a warm climate, at the same time that in the west the triassic reptiles before mentioned were swarming on the land and in the rivers and estuaries. This St. Cassian fauna is known to extend as far north as lat. 55°, and has been traced as far south in India as the Himalaya mountains in lat. 30°, showing that the elevated temperature alluded to was of wide geographical extent.

Triassic conglomerate.—The great size of some fragments of rock in the New Red Sandstone, probably of Triassic age, in Devonshire, has led Mr. Godwin-Austen to refer their transport to ice-action; but this opinion has been controverted by Mr. Pengelly,* who has shown that such masses

* See his Paper on the Red Sandstone Conglomerates of Devonshire, part ii.

may not have travelled far, and are such as might have been moved by breakers beating against a wasting cliff.

Permian fossils.—Between the Triassic and Permian rocks there is a break which doubtless implies a great lapse of time, of which the records are wanting, in that part of the globe as yet best known to the geologist. It constitutes the line of division between the primary and secondary, or between the Mesozoic and Palæozoic formations. The Permian rocks have been traced as far north as Petschora-land in Russia between lat. 65° and 70° N. They occur largely in Germany and England; and in North America have been traced as far south as Kansas and Nebraska, lat. 44° N.

Amongst the Permian shells we find the genera Nautilus and Orthoceras, and these are sometimes accompanied by large reptiles of a family called Thecodonts, which combine in their structure many characters of the living crocodiles and lacertians. They are most nearly allied to the Varanians or Monitors, which now inhabit tropical countries. The fossil plants of the Permian formation are very like those of the antecedent carboniferous strata, of which I shall presently speak, and indicate the prevalence of a warm and moist climate throughout a great part of the northern hemisphere.

Supposed signs of ice-action in the Permian Period.—Professor Ramsay, in an able memoir published in 1855, gave an account of observations made by him on a brecciated conglomerate of Permian age in Shropshire, Worcestershire, and other parts of England, which had led him to infer the action of floating ice in the seas of that remote period. His arguments are founded on the following facts:—the fragments of various rocks imbedded in these breccias are often angular, and of large size, some of them weighing more than half a ton; they are very often flat-sided, and have one or more of their surfaces polished and striated. They are generally enveloped in a red unstratified marl, in which they lie confusedly, like stones in boulder-drift. In some cases it can be demonstrated that the nearest points from which these stones could possibly have been conveyed are the mountains of Wales, more than twenty, thirty, or even

fifty miles distant; and it is inferred that the only way in which they could have retained their angular shape, after being transported so far from their original position, is by being carried by floating ice. Some of the specimens also taken by the Professor out of the breccia, and now exhibited in London, in the Jermyn Street Museum, have their surfaces rubbed, flattened, and furrowed, like stones subjected to glacial action. One of the most characteristic of these specimens was obtained from a spot about six miles south-east of Bridgenorth, near the village of Enville in Worcestershire. The fragment is six inches in its longest diameter, consists of hard dark Cambrian grit, with a smoothed surface, exhibiting parallel sets of striæ in more than one direction,* a newer set crossing the older one. I am fully satisfied that such fragments have been taken out of the breccia, and the explanation offered by Professor Ramsay appears to me the most natural, indeed the only one in the present state of science which can be suggested. That glaciers should have reached the sea in lat. 53°, in England, cannot surprise us when we see them coming down at present to within 500 feet of the sea in New Zealand, in lat. 44°, or much nearer the equator; and it has been already stated (p. 210) that tree-ferns and even palms now flourish in New Zealand, in the immediate neighbourhood of these glaciers. It should also be borne in mind, that there is a great dearth of fossil remains in the Permian conglomerates of Central England; and we know not by what plants or animals the lands and seas were inhabited at the time of their accumulation, and, consequently, we are ignorant, so far as we depend on organic evidence, of the nature of the climate which prevailed in that part of the Permian era, when the stones which have apparently been glaciated were carried to their present sites. Professor Suess, who has studied the Permian conglomerate or Rothliegende in various parts of the Alps, says that it shows signs of great denudation of pre-existing land by the large quantity of quartz pebbles which it contains, but hitherto no signs of ice-borne rocks have there been met

* Ramsay, Quart. Geol. Journ., vol. ii. 1855.

with. The Alpine localities, however, are about 5° south of those alluded to in Great Britain.

Climate of Carboniferous Period—fossil plants.—If we next consider the climate of the Carboniferous period, we shall find that botanists have considerably modified the ideas which they originally entertained respecting the tropical temperature supposed to be indicated by the fossil plants of that era. The fruit called Trigonocarpon, occurring in such profusion in the coal measures, was at first referred to the palm tribe, till the discovery of more perfect specimens enabled Dr. Hooker to decide that it was not a palm, but more probably belonged to a taxoid conifer, somewhat like the Chinese Salisburia. The structure of the coniferous wood preserved in these strata exhibits some points of analogy with the Araucariæ of Chili, Brazil, New Holland, and Norfolk Island.

M. Adolphe Brongniart has observed that the great numerical preponderance of ferns over other forms of vegetation in the Carboniferous era gives us ground to conclude that the climate was warm and moist. It must be confessed that this reasoning loses some of its force when we consider that the ancient flora is almost entirely destitute of those flowering plants which now constitute three-fourths of the living vegetation. The ferns of the Coal period had fewer rivals to compete with, and more space in which to develop themselves freely; still the fact that many of them belong to arborescent genera, such as Caulopteris, Zippea, Sphalmopteris, and Stemmatopteris, would incline us to think, according to the analogy of the living creation, that the climate was warm, moist, and equable, for tree-ferns are now most abundant in islands of the tropical ocean, although some species extend in New Zealand, as before stated, as far towards the antarctic regions as the 46th degree of south latitude. A warm climate seems also implied by the other vascular cryptogams which, together with the ferns, from nineteen-twentieths of the carboniferous flora. They belong to families allied to ferns, such for example as the Sigillariæ, Lepidodendra, and Calamites, and most of them attained a vastly greater size, growing even to the height of forest trees, and had a more complex structure, than any of their modern

representatives. Their stems had also a lax tissue and, like living cryptogams of the same families, they must have derived the greater part of the water which entered into their composition, as well as their carbon, by their leaves from the air. They probably flourished, therefore, in an atmosphere highly charged with aqueous vapour, and such an atmosphere must have been warm. Yet we must not suppose the heat to have been tropical, for hot sunshine, by promoting the decomposition of vegetable matter, is adverse to the formation of coal as it is to that of peat.

As to the geographical range in the northern hemisphere of this ancient flora, it is already ascertained that it extends from Alabama in the United States in lat. 30° to the arctic regions, while it has been traced in Europe from central Spain in lat. 38° to Scotland in lat. 56°. In the arctic regions it was first observed in Melville Island, in lat. 75°, during Capt. Parry's expedition. The plants then collected were examined by the late Dr. Lindley, who recognised them as true fossils of the ancient coal.* The original collection has unfortunately been lost, but among other fossils since brought from the same island by Sir Leopold McClintock, Heer has recognised ferns of the genus *Schizopteris*, a form characteristic of the ancient coal. Middendorf found *Calamites cannæformis* in a very high latitude near the mouths of the Lena. Von Buch has described strata of the Coal period containing characteristic marine fossils in Bear Island, lat. 74° 36′ N., midway between Spitzbergen and the North Cape, in about the same parallel as Melville Island; and from associated rocks of the same age and in the same locality Heer has received as many as fifteen species of plants well known as occurring in different stages of the European Carboniferous formation.†

After what was said at p. 201 of the spread of the Miocene flora over the arctic regions, and its near approach to the North Pole, the reader will feel no surprise at finding that in times long antecedent there was an equally vigorous vegetation in the same latitudes. Moreover, the coal plants

* Penny Cyclopædia, art. Coal Plants. † Student's Elements, p. 424.

were of different genera, and some few of them perhaps of different orders, from any now existing, and they may therefore have been endowed with a constitution enabling them to accommodate themselves to a long polar night.

We know, by experiment, that plants which are natives of the tropics can dispense more easily with the bright light of those countries than with the heat of the same. Few palms can live in our temperate latitudes without protection from the cold; but when placed in hot-houses they grow luxuriantly, even under a cloudy sky, and where much light is intercepted by the glass and framework. At St. Petersburg, in lat. 60° N., many tropical plants have been successfully cultivated in hot-houses, although there they must exchange the perpetual equinox of their native regions for days and nights which are alternately protracted to nineteen hours and shortened to five. How much farther towards the pole even the existing species might continue to live, provided a due quantity of heat and moisture were supplied, has not yet been determined; but St. Petersburg is probably not the utmost limit, and we should expect that in lat. 65° at least, where they would never remain twenty-four hours without enjoying the sun's light, they might still exist.

Supposed excess of carbonic acid in the air.—That the air was charged with an excess of carbonic acid in the Coal period has long been a favourite theory with many geologists, who have attributed partly to that cause an exuberant growth of plants. It has been said that there is ten times more carbon locked up in a solid form in the ancient coal-measures than all that is now contained in the atmosphere; but granting the truth of this estimate, which is probably far below the mark, the soundness of the inference has always appeared to me most questionable. The atmosphere now receives large supplies of carbonic acid by gaseous emanations from the interior of the earth, which are most copiously given out in volcanic regions, and especially by volcanos during eruptions. Carburetted hydrogen also escapes from beds of coal and lignite and other fossiliferous strata in which organic matter is decomposing; the same gas evidently rising from great depths is also evolved from rents in the granitic and other crystalline

rocks in which there are no organic remains. But it does not follow that the air is becoming more and more loaded with carbonic acid, for there are causes in action which prevent such a change in the constitution of the atmosphere. Wherever drift-timber is buried in the delta of a river, sea, or lake, or wherever peat is forming, we behold the process by which carbon is first extracted by the powers of vegetation from the atmosphere, and then locked up permanently, or for ages, in the earth's crust. As to the volume of carbonaceous matter which may thus be accumulated, it is a mere question of the time for which certain species of plants, together with the conditions fit for making peat and for burying drift-timber, may endure.*

Some botanists are of opinion that the Sigillaria in the Carboniferous period played the same part which is now performed by the Sphagnum in Europe, both of them tending to relieve the atmosphere of part of the carbonic acid which is incessantly evolved from the interior of the earth. Mr. Darwin attributes the small quantity of peat formed in some regions of South America which are exceedingly damp to the absence of species of plants peculiarly fitted for its production. The abundance of coal, therefore, in certain districts may have arisen from the peculiarity of the vegetation, and of a climate which prevented decomposition, rather than from a peculiarity in the atmosphere which enveloped the globe in the Carboniferous period. In the Runn of Kutch there is a great annual deposit of salt caused by the evaporation of sea-water; but this arises from geographical causes wholly unconnected with the chemical condition of the ocean, which is not supposed to contain in that part of India more than its average proportion of chloride of sodium. The quantity of rock salt stored up in the Runn of Kutch, if that large district should be slowly subsiding, may in time exceed in amount all the brine now held in solution by the ocean, but if so, future geologists will have no right to conclude that during such an accumulation of chloride of sodium the waters of the sea generally were more salt than they usually are. Nay, it would be even safer to conclude that during the period when

* See below, Chap. XVII.

so much rock salt was forming, the waters of the ocean would contain less than their average quantity of brine.

Fossil shells and corals of the Carboniferous Period.—If we now turn from the flora to the fauna of the Carboniferous period, we find among the invertebrate animals many large chambered shells of Cephalopoda, such as Nautilus, Orthoceras, and others, as well as stone-lilies or encrinites, and corals, all of which families flourished in those secondary periods, when for reasons already explained, a warm climate is supposed to have prevailed. It may indeed be objected, in regard to the corals, that they all belong to types only met with in the primary or palæozoic rocks; that is to say, to the orders *Zoantharia rugosa* and *Z. tabulata* of Milne-Edwards, which with one exception became extinct after the Permian era; but it must be remembered that these Palæozoic cup and star corals of the older or quadripartite type have such a range, from tropical to northern regions, that we must either suppose them to have had greater powers of adaptation to differences of climate, or that the seas of high and low latitudes had a more equable temperature than they have now.

Carboniferous Amphibia.—No representatives of the Vertebrata have been found in the Carboniferous formation except reptiles and fish. The species of the former class are confined to two extinct orders, *Ganocephala* and *Labyrinthodontia*, which are represented by thirteen genera in the coal-measures of England and Ireland. Both of these depart widely from living types, but approach most nearly to the tailed batrachians of our time, to which the salamanders and certain perennibranchiate batrachians belong. All these are members of the sub-class Amphibia, which are regarded by many zoologists as intermediate between true reptiles and fish. Their nearest living allies are only found at present in the northern hemisphere, where they have, according to Mr. Gunther, a wide range from north to south, in America, as well as Europe and Asia. They are most numerously represented in genera, species, and individuals in the Southern United States, and on the table-land of Mexico. In Guatemala we find that in lat. 15° N. they have already become scarce, being reduced to one or two

forms. As to their extension in the opposite direction, some small species occur in the Canadian lakes; one of these, of the Menobranchus family, *Giredon hiemalis*, having been observed as far north as Lake Superior, in a place where the water was frozen over an inch thick every night for three months.* Such a geographical distribution is confirmatory of the conclusions as to climate to which we have been led by the plants of the Carboniferous era, as the tailed batrachians attain their fullest development between the 20th and 40th degrees of latitude, or in a warm zone free from intense heat or cold.

Devonian Period.—In the antecedent Devonian period there are no reptiles, not even any of the order Amphibia. There are abundance of Ganoid fish, which have their nearest living analogues in the rivers of Northern Africa, for they are closely related to the African Polypterus, of which several species are found in the Nile, and others in the rivers of Senegal. The associated Placoid fish belong also to a family found chiefly in equatorial regions, though having a wide range into cooler latitudes. The Devonian, or Old Red crustaceans, such as Pterygotus and Eurypterus, attain some of them a length of five or six feet, and are therefore most comparable, in size at least, to crustaceans such as the King Crab, now living in Japan and America, and in regions still nearer the equator. The mollusca and corals resemble generically those of the Carboniferous period. The Devonian flora is chiefly known to us through the labours of American geologists in the State of New York, and in Canada as far north as lat. 49°. More than sixty American species are enumerated by Dr. Dawson from that continent, and they comprise so large a portion of the carboniferous genera, including tree-ferns, as to point to a similarity of climate. The same may be said of the European plants of corresponding age, so far as they are known.

Supposed signs of ice-action in the Old Red Sandstone, or Devonian Period.—The Rev. J. G. Cumming, in 1848, in his History of the Isle of Man, compared the conglomerate of the Old Red Sandstone to 'a consolidated ancient boulder clay;'

* Dr. Samuel Kneeland, Proceed. Boston Soc. Nat. Hist., vol. vi. p. 152.

and more recently (1866), Professor Ramsay has pointed out that the conglomerate of the same age seen at Kirkby-Lonsdale, and Sedbergh, in Westmorland and Yorkshire, contains stones and blocks distinctly scratched, and with longitudinal and cross striations, like the markings produced by glacial action. I have myself examined this rock, and have seen blocks taken from it which exhibit such markings, some of them undistinguishable from those which I have observed on blocks taken from beneath a glacier. But Professor Ramsay has himself adverted to the fact, that the conglomerate above alluded to has been subjected to violent movements in different directions, and to great pressure after it was buried under thousands of feet of carboniferous strata. In consequence of these movements, some markings have been produced within the body of the rock itself, one pebble having occasionally been squeezed and forced against another, so as to indent it. Many of the pebbles also, and stones two feet and more in diameter, have acquired that polish which is called slickenside; and the same may be seen in various parts of the marly matrix. We must not forget that the district in question is exactly in the line of a great system or succession of faults, so that here there has been an unusual repetition of movement and dislocation of rock, which makes it difficult to decide in many cases to what kind of mechanical action the effects alluded to have been due. More evidence, I think, must be obtained before we can feel perfectly convinced that the markings in question have had a glacial origin.

Climate of the Silurian Period.—When we enquire into the climate of the Silurian and still older formations, we find ourselves deprived of some important classes of evidence on which we have relied when considering the organic remains of the formations of later date. Reptiles fail us entirely, as in the Devonian rocks; fish are wanting, except a few remains in the Upper Silurian; of plants there are none, save a few doubtful fucoids and a few cryptogamic sporangia in the Upper Ludlow; we must therefore be content to form our opinion as to the state of the climate from those genera of invertebrate animals of which there is a great profusion,

but which usually in the primary strata depart widely from tertiary and living types. Of the probable bearing on climate of the large crustaceans of the genera Eurypterus and Pterygotus I have already spoken when treating of the Devonian beds, and we find them equally well represented by other species of the same genera in the higher beds of the underlying Silurian. The numerous trilobites, large chambered cephalopods, the corals, and the crinoids are also so like those of the newer members of the Palæozoic series as to make us incline to believe that a similar climate prevailed in the northern hemisphere, and a somewhat uniform temperature from equatorial to very high latitudes. In speculating, however, on this subject, we must not forget that much light has recently been thrown by deep-sea dredging on the uniformity of temperature which may prevail in the ocean from high to low latitudes, at depths now known to be inhabited, though formerly supposed to be below the zero of animal life.

Concluding remarks on Climate.—The result then of our examination in this and in the preceding chapter of the organic and inorganic evidence as to the state of the climate of former geological periods is in favour of the opinion that the heat was generally in excess of what it now is. There have been oscillations of temperature, and at least one period of excessive cold of comparatively modern date. In the greater part of the Miocene and preceding Eocene epochs the fauna and flora of Central Europe were subtropical, and a vegetation resembling that now seen in Northern Europe extended into the arctic regions as far as they have yet been explored, and probably reached the pole itself. In the Secondary or Mesozoic ages, the predominance of reptile life, and the general character of the fossil types of that great class of vertebrata, indicate a warm climate and an absence of frost between the 40th parallel of latitude and the pole, a large ichthyosaurus having been found in lat. 77° 16′ N. The great development also of the tetrabranchiate and dibranchiate cephalopoda, with the general character of the mollusca and corals, as well as of the plants, is in perfect accordance with the

inferences deduced from the associated fossil reptiles. If we then carry back our retrospect to the primary or Palæozoic ages, we find an assemblage of plants which imply that a warm, humid, and equable climate extended in the Carboniferous period uninterruptedly from the 30th parallel of latitude to within a few degrees of the pole, or to northern regions where at present the severe winter's frost, and the almost universal covering of snow lasting for many months, preclude the existence of a luxuriant vegetation. A still older flora, the Devonian, so far as we have yet traced its geographical extension, leads to similar inferences, and the invertebrate fauna of the Devonian, Silurian, and Cambrian rocks has such a generic resemblance to that of the Carboniferous, Permian, and Triassic periods as to imply that a similarity of conditions in regard to temperature prevailed throughout the whole of these six periods.

As to the supposed indications of ice-action in the Miocene and Eocene and the still remoter Permian periods, the reader must not forget the caution already given (p. 210), that should we meet with erratic blocks of the largest size, having one or more glaciated surfaces, included in sedimentary strata between latitudes 40° and 50°, these blocks may have been carried to their present destination without the aid of glacial conditions more intense than those now supplied by the present state both of the northern and southern hemispheres. We learn from Captain Evans's ice-chart * that in January 1850 icebergs reached even to the Cape of Good Hope, in lat. 35° S.; and we shall see in Chapter XVI. that large erratic blocks have been seen imbedded in icebergs floating far from land in the southern seas.

* Admiralty Charts, 1865, No. 1241. See also p. 249.

CHAPTER XII.

VICISSITUDES IN CLIMATE CAUSED BY GEOGRAPHICAL CHANGES.

ON THE CAUSES OF VICISSITUDES IN CLIMATE—ON THE PRESENT DIFFUSION OF HEAT OVER THE GLOBE—MEAN ANNUAL ISOTHERMAL LINES—DEPENDENCE OF THE MEAN TEMPERATURE ON THE RELATIVE POSITION OF LAND AND SEA—CLIMATE OF SOUTH GEORGIA AND TIERRA DEL FUEGO—COLD OF THE ANTARCTIC REGION—OPEN SEA NEAR THE NORTH POLE—EFFECT OF CURRENTS IN EQUALISING THE TEMPERATURE OF HIGH AND LOW LATITUDES—THE PRESENT PROPORTION OF POLAR LAND ABNORMAL—SUCCESSION OF GEOGRAPHICAL CHANGES REVEALED TO US BY GEOLOGY—MAP SHOWING THE AMOUNT OF EUROPEAN LAND WHICH HAS BEEN UNDER WATER SINCE THE COMMENCEMENT OF THE EOCENE PERIOD—ANTIQUITY OF THE EXISTING CONTINENTS—CHANGES IN GEOGRAPHY WHICH PRECEDED THE TERTIARY EPOCH—MAP SHOWING THE UNEQUAL DISTRIBUTION OF LAND AND WATER ON THE GLOBE—FORMER GEOGRAPHICAL CHANGES WHICH MAY HAVE CAUSED THE FLUCTUATIONS IN CLIMATE REVEALED TO US BY GEOLOGY—IDEAL MAP WITH THE EXCESS OF LAND REMOVED FROM POLAR TO TROPICAL REGIONS—GREAT DEPTH OF THE SEA AS COMPARED TO THE MEAN HEIGHT OF THE LAND, AND ITS CONNECTION WITH THE SLOWNESS OF CLIMATAL CHANGES.

Causes of vicissitudes in climate.—As our retrospective survey of the fossiliferous rocks of successive periods, given in the last two chapters, has led us to infer that the earth's surface has experienced great changes of climate since it has been inhabited by living beings, we have next to enquire how such vicissitudes can be reconciled with the existing order of nature. The earlier speculators in geology availed themselves of this, as of every obscure problem, to confirm their views concerning a period when the planet was in a nascent or half-formed state, or when the laws of the animate and inanimate world differed essentially from those now established; and in this, as in many other cases, they succeeded, to no small extent, in diverting attention from that class of facts which, if fully understood, might have led the way to an explanation of the phenomena. At first it was imagined that the earth's axis had been for ages perpendicular to the

plane of the ecliptic, so that there was a perpetual equinox, and uniformity of seasons throughout the year; that the planet enjoyed this 'paradisiacal' state until the era of the great flood; but in that catastrophe, whether by the shock of a comet, or some other convulsion, it lost its equipoise, and hence the obliquity of its axis, giving rise to the varied seasons of the temperate zone, and the long nights and days of the polar circles.

When the progress of astronomical science had exploded this theory, it was assumed, that the earth at its creation was in a state of igneous fluidity, and that, ever since that era, it had been cooling down, contracting its dimensions, and acquiring a solid crust. It was also taken for granted that this original crust was the same as that which we are now studying, and which contains the monuments of a long series of revolutions in the animate world. This notion, however arbitrary, was well calculated for lasting popularity, because it referred the mind directly to the beginning of things, and required no support from any ulterior hypothesis. But the progress of geological investigation gradually dissipated the idea, at first universally entertained, that the granite or crystalline foundations of the earth's crust were of older date than all the fossiliferous strata. It has now been demonstrated that this opinion is so far from the truth that it is difficult to point to a single mass of volcanic or plutonic rock which is more ancient than the oldest known organic remains. Such being the case, the question of original fluidity, although a matter of legitimate speculation to the physicist, is one with which the geologist is but little concerned. It may relate to a state of things which preceded our earliest records by a lapse of ages many times greater than the entire series of geological epochs with which we are acquainted.

If, instead of indulging in conjectures as to the state of the planet at the era of its creation, we fix our thoughts steadily on the connection at present existing between climate and the distribution of land and sea, and then consider what influence former fluctuations in the physical geography of the globe must have had on superficial temperature, we may

make a near approximation to a true theory. But the effect of former variations in the heat and cold of the different seasons in the year, caused by the precession of the equinoxes, combined with the revolution of the apsides, and still more by variations in the excentricity of the earth's orbit, will have to be taken into account, as subsidiary to the more dominant influence of geographical conditions. Should doubts and obscurities still remain, they should be ascribed to our limited acquaintance with the laws of Nature, not to revolutions in her economy. They should stimulate us to farther research, not tempt us to indulge our fancies respecting imaginary changes of internal temperature, or the unsettled state of the surface of a planet before it was prepared for the habitation of living beings.

Diffusion of heat over the globe.—In considering the laws which regulate the diffusion of heat over the globe, we must be careful, as Humboldt well remarks, not to regard the climate of Europe as a type of the temperature which all countries placed under the same latitude enjoy. The physical sciences, observes this philosopher, always bear the impress of the places where they began to be cultivated; and as, in geology, an attempt was at first made to liken all the volcanic phenomena to those of Italy, so in meteorology, a small part of the old world, the centre of the primitive civilisation of Europe, was for a long time considered a type to which the climate of all corresponding latitudes might be referred. But this region, constituting only one-seventh of the whole globe, proved eventually to be the exception to the general rule. For the same reason, we may warn the geologist to be on his guard, and not hastily to assume that the temperature of the earth in the present era is a type of that which most usually obtains, since he contemplates far mightier alterations in the position of land and sea, at different epochs, than those which now cause the climate of Europe to differ from that of other countries in the same parallels of latitude.

It is now well ascertained that zones of equal warmth, both in the atmosphere and in the waters of the ocean, are neither

parallel to the equator nor to each other.* It is also known that the *mean* annual temperature may be the same in two places which enjoy very different climates, for the seasons may be nearly uniform, or violently contrasted, so that the lines of equal winter temperature do not coincide with those of equal annual heat or isothermal lines. The deviations of all these lines from the same parallel of latitude are determined by a multitude of circumstances, among the principal of which are the position, direction, and elevation of the continents and islands, the position and depths of the sea, and the direction of winds and currents.

On comparing the two continents of Europe and America, it is found that places in the same latitude have sometimes a mean difference of temperature amounting to 11°, or even in a few cases to 17° Fahr.; and some places on the two continents, which have the same mean temperature, differ from 7° to 17° in latitude. Thus, Cumberland House, in North America (see fig. 9, p. 240), having the same latitude (54° N.) as the city of York in England, stands on the isothermal line of 32°, which we have to seek in Europe at the North Cape, in lat. 71°, but its summer heat exceeds that of Brussels or Paris.† The principal cause, says Humboldt, of the greater intensity of cold in corresponding latitudes of North America, as contrasted with Europe, is the connection of America with the polar circle, by a large tract of land, some of which is from three to five thousand feet in height; and, on the other hand, the separation of Europe from the arctic circle by an ocean. The ocean has a tendency to preserve

* We are indebted to Alex. von Humboldt for having first collected together the scattered data on which he founded an approximation to a true theory of the distribution of heat over the globe. Many of these data were derived from the author's own observations, and many from the works of M. Pierre Prévost, of Geneva, on the radiation of heat, and from other writers.—See Humboldt on Isothermal Lines, Mémoires d'Arcueil, tom. iii. translated in the Edin. Phil. Journ. vol. iii. July 1820.

The map of Isothermal Lines, published by Humboldt and Dove in 1848 (re-edited by Dove in 1853, from which fig. 9 is extracted), supplies a large body of well-established data for such investigations, of which Mr. Hopkins availed himself in an able essay 'On the Causes which may have produced Changes in the Earth's Superficial Temperature.'—Q. Journ. Geol. Soc. 1852, p. 56.

† Sir J. Richardson's Appendix to Sir G. Bach's Journal, 1843–1845, p. 478.

everywhere a mean temperature, which it communicates to the contiguous land, so that it tempers the climate, moderating alike an excess of heat or cold. The elevated land, on the other hand, rising to the colder regions of the atmosphere, becomes a great reservoir of ice and snow, arrests, condenses, and congeals vapour, and communicates its cold to the adjoining country. For this reason, among others, Greenland, forming part of a continent which stretches northward to the 82nd degree of latitude, experiences under the 60th parallel a more rigorous climate than Lapland under the 72nd parallel.

But if land be situated between the 45th parallel and the equator, it produces, unless it be of great height, exactly the opposite effect; for it then warms the tracts of land or sea that intervene between it and the polar circle. For the surface being in this case exposed to the vertical or steeply sloping rays of the sun, absorbs a large quantity of heat, and raises the temperature of the atmosphere which is in contact with it. For this reason, the western parts of the old continent derive warmth from Africa, 'which, like an immense furnace, distributes its heat to Arabia, to Turkey in Asia, and to Europe.'* The north-eastern extremity of Asia, on the contrary, experiences in the same latitude extreme cold; for it has the land of Siberia on the north between the 65th and 70th parallel, while to the South it is separated from the equator by the Pacific Ocean.

A large proportion of the sun's heat is employed in the tropics in changing water from the liquid to the gaseous state, being thus absorbed without affecting the thermometer. The moist aërial currents, therefore, which take their rise over the ocean and damp regions of equatorial land, carry a large quantity of latent heat to more northern latitudes, which is set free as the wind cools and precipitates its vapour in the form of water or snow. 'Thus aqueous vapour,' says Herschel, 'becomes an agent in the transfer of heat, in its latent state, from one part of the globe or from one region of the atmosphere to another.'† The upper trade winds (or anti-trades), which pass freely above the peaks of all but the

* Malte-Brun, Phys. Geol. book xvii. † Herschel, Meteorology, 1862, art. 51.

highest mountains, are able to pursue an almost unbroken course over tropical and subtropical latitudes, until they come to those more northern regions where the act of condensation releases probably as much as three-fourths of their heat. The surface of the land is sometimes raised to a temperature of 159° F. in South Africa, and perhaps even higher in Australia (see p. 283), while the surface of the ocean is rarely heated over 80° F. The effect therefore of land at the equator will be to cause the hot air to rise with much greater velocity than it would off the ocean, and to carry rapidly, from localities moist enough to provide it with aqueous vapour, a large volume of heat to more northern latitudes. We must not forget also that, besides this action at great heights of what has been called the upper trade winds, aërial currents, such as the well-known Scirocco in Italy and the Föhn in Switzerland, blowing from tropical to temperate regions at a lower level, occasionally cause the rapid melting of the snows of the Apennines and Alps.

In July 1841, according to M. Denzler, the Föhn blew tempestuously at Algiers, and, crossing the Mediterranean, in six hours reached Marseilles, and in five hours more it was at Geneva and the Valais, throwing down a large extent of forest in the latter district, while in the cantons of Zürich and the Grisons it suddenly turned the leaves of many trees from green to yellow. In a few hours new-mown hay was dried and ready for the haystack. The snow-line of the Alps was seen by M. Irscher the astronomer, from his observatory at Neufchâtel, by aid of the telescope, to rise sensibly every day while the Föhn was blowing. Its influence is by no means confined to the summer season, for in the winter of 1852 it visited Zürich at Christmas, and in a few days all the surrounding country was stripped of its snow, even in the shadiest places and on the crests of high ridges; and Escher von der Linth has pointed out that, in proportion to the number of days that this dry wind blows, the Alpine glaciers advance or retreat in particular years.

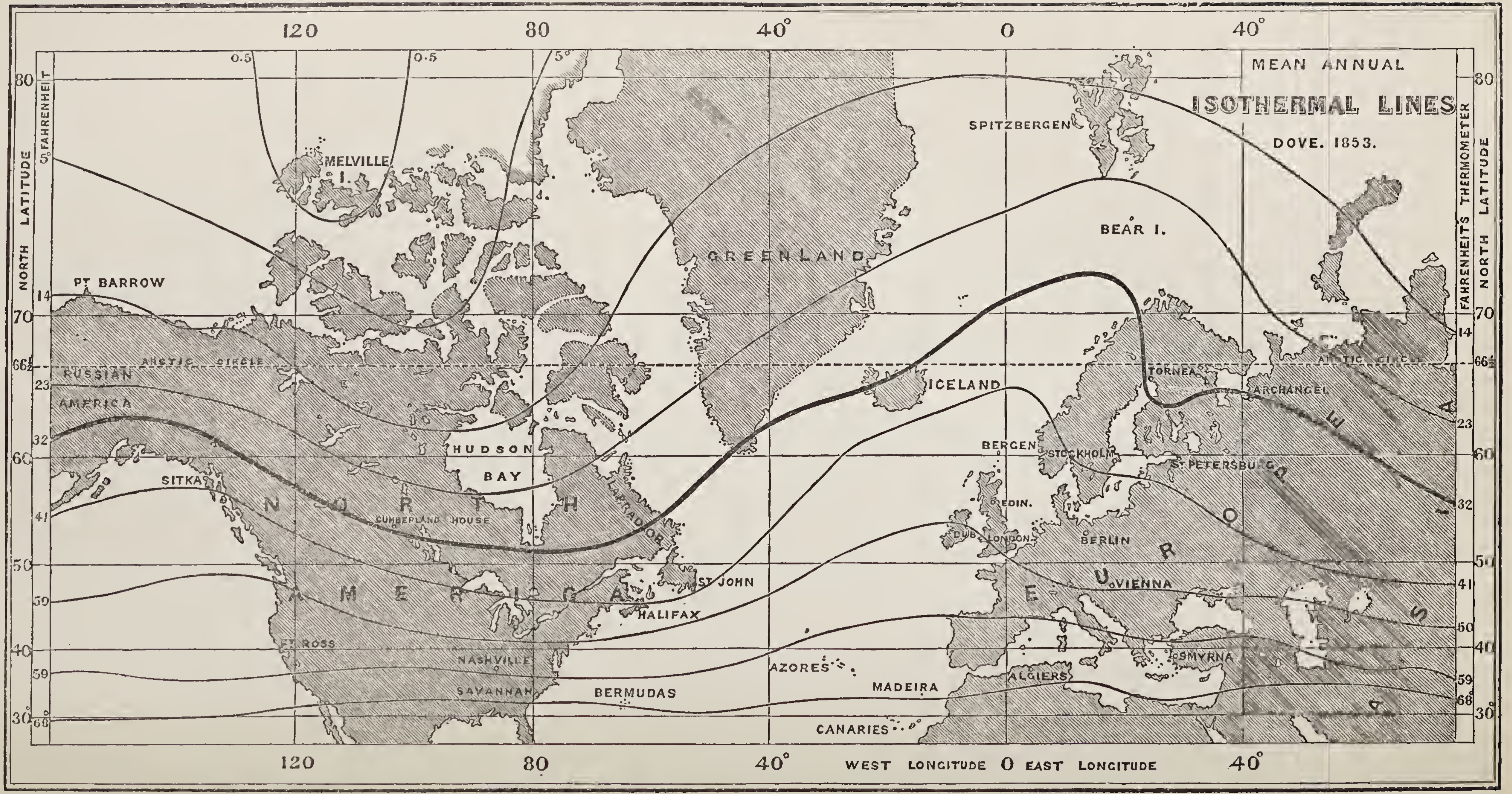
Another way in which the winds have a powerful, though indirect, influence on climate is by giving origin to the principal currents of the ocean. Humboldt, as we have seen (p. 237), assigned as a cause for the rigorous climate of Greenland,

that it is connected with more northern latitudes by elevated land. But, besides this reason, it must be borne in mind that the eastern coast of that country is skirted for a thousand miles by the cold waters of the Greenland current flowing from the North Pole, while Lapland is warmed by the waters of the Gulf-stream flowing from the south.

It will be seen at p. 246 how much warmth is conveyed by this stream to the west of Europe, but the point which concerns us here is that, if the land now at the equator in the region where the upper trade wind gains its heat and force were replaced by ocean, the supply of hot air would be less, and the average velocity of the trade winds would be diminished. Now the equatorial current of the North Atlantic is heaped up in the Caribbean Sea in a great measure by the confluent northern and southern trades, and any diminution in this force must lessen the head of water in the Gulf of Mexico, and consequently the force of the Gulf-stream. There can be little doubt therefore that the present abnormal preponderance of land at the equator has a great effect in raising the temperature of the surface of the globe, both by its continuity from tropical to temperate regions, and by its influence in increasing the warm aërial and oceanic currents.

In consequence of the more equable temperature of the waters of the ocean, the climate of islands and of coasts differs essentially from that of the interior of continents, the more maritime climates being characterised by mild winters and more temperate summers; for the sea breezes moderate the cold of winter, as well as the heat of summer. When, therefore, we trace round the globe those belts in which the mean annual temperature is the same, we often find great differences in climate; for there are *insular* climates in which the seasons are nearly equalised, and *excessive* climates, as they have been termed, where the temperature of winter and summer is strongly contrasted. The whole of Europe, compared with the eastern parts of America and Asia, has an 'insular' climate. The northern part of China, and the Atlantic region of the United States, exhibit 'excessive climates.' We find at New York, says Humboldt, the summer of Rome and the winter of Copenhagen; at Quebec, the

Fig. 9.



MEAN ANNUAL
ISOTHERMAL LINES
DOVE. 1853.
NORTH LATITUDE
FAHRENHEIT
FAHRENHEIT'S THERMOMETER
WEST LONGITUDE 0 EAST LONGITUDE
120
80
40°
0
40°
MELVILLE I.
SPITZBERGEN
BEAR I.
GREENLAND
PT BARROW
ARCTIC CIRCLE
RUSSIAN AMERICA
HUDSON BAY
ICELAND
TORNEA
ARCHANGEL
BERGEN
STOCKHOLM
ST PETERSBURG
SITKA
NORTH AMERICA
CUMBERLAND HOUSE
LABRADOR
EDIN.
DUB.
LONDON
BERLIN
EUROPE
ASIA
ST JOHN
HALIFAX
VIENNA
FT ROSS
NASHVILLE
SAVANNAH
BERMUDAS
AZORES
MADEIRA
ALGIERS
SMYRNA
CANARIES

summer of Paris and the winter of Petersburg. At Pekin in China, where the mean temperature of the year is that of the coasts of Brittany, the scorching heats of summer are greater than at Cairo, and the winters as rigorous as those of Upsala.

Mean annual isothermal lines.—If lines be drawn round the globe through all those places which have the same winter temperature, they are found to deviate from the parallels of latitudes much farther than the lines of equal mean annual heat. The lines of equal winter in Europe, for example, are often curved so as to reach parallels of latitude 9° or 10° distant from each other, whereas the isothermal lines of that continent, or those passing through places having the same mean annual temperature, differ only from 4° to 5°. If the reader will turn to the annexed map (fig. 9) by Professor Dove, he will see that the isothermal line of 32° Fr. or the freezing point of fresh-water, curves so as to vary as much as 14 degrees of latitude in passing from east to west, or from the south of Asiatic Russia (lat. 56°) to the north of Norway (lat. 70°). The same line then trends southward from Norway to Iceland, and passing to the southernmost point of Greenland, in lat. 60°, continues its course south-westwards to the south of Hudson's Bay, lat. 51° 15′, a point more than 18 degrees south of that which it had reached in the arctic sea. It then inclines again northwards through N. America to Behring's Straits.

The isothermal of 14° Fahr. is equally remarkable: passing from Siberia, about 50 miles south of Yakutsk, lat. 62° 2′ north, (which lies to the east of the limits of our map,) it inclines northwards to the north of Spitzbergen, in lat. 79°, then passes southwards through the north of Greenland, to 63°, in Hudson's Bay, reaching the same parallel from which it started in Siberia, then again it inclines north-westwards beyond the arctic circle till it reaches Point Barrow in Russian America, lat. 71° 40′. From such facts it is obvious that the curves of those lines in the same hemisphere which represent the same mean annual temperature are by no means dependent on astronomical causes or on latitude alone.

Dependence of the mean temperature on the relative position of land and sea.—When the meteorologist enquires into the state of things south of the equator, he finds the contrast of the temperature prevailing in certain lands similarly situated as regards their distance from the pole, equally striking, notwithstanding that, on the whole, there is a greater uniformity of climate in the southern hemisphere, in consequence of a greater predominance of sea over land. The most remarkable illustration of this contrast is afforded by the island of South Georgia, 800 miles due east of Tierra del Fuego, in latitude 54° S., or at the same distance from the equator as Yorkshire. Captain Cook, speaking of this island, says, in his second voyage, that in January (corresponding to our July) they never had the temperature more than 10° F. above freezing, and snow fell occasionally in the same month, the perpetual snows descending to the level of the ocean. No trees or shrubs were to be seen in summer, although here and there, after a partial melting of the ice on the coast, a few rocks were scantily covered with moss and tufts of grass.*

This state of things is remarkable when we reflect that the highest mountains in Scotland, nearly 4,500 feet high, and four degrees nearer the pole, do not retain snow even on their summits throughout the year; and Principal J. D. Forbes observed, that there is no place as yet known in the northern hemisphere where the snow-line comes down to the level of the sea.† The exact height of the mountains in S. Georgia is not known, but they are described as being very high, and in Sandwich Land, five degrees to the south, in a latitude corresponding nearly to the north of Scotland, mountains 10,000 feet high have been observed, and in those islands, on the 1st of February, the hottest time of the year, the whole country from the top of the mountains to the brink of the sea-cliffs was covered with snow many fathoms thick.

It was stated that Tierra del Fuego is only 800 miles west-

* Mr. Hopkins raises the question whether, in South Georgia, the descent of glaciers to the margin of the sea might not have been mistaken by Capt. Cook for the descent of the snow-line to the sea-level. Quart. Journ. Geol. Soc. p. 85. 1852. But the great navigator is generally so accurate that I see no reason for calling his statements in question.

† J. D. Forbes, Norway, p. 205.

ward of S. Georgia. As it is in the same latitude, as well as in the same hemisphere, the contrast in climate which it presents must be quite independent of what we may term astronomical causes. In Tierra del Fuego the lower limit of the snow-line ascends, according to Darwin, to between 3,000 and 4,000 feet above the level of the sea, and there are forests on the flanks of the hills to a height of 1,000 or 1,500 feet.* There are many flowers in the same region and humming-birds in summer, yet a high range of land runs across the middle of Tierra del Fuego from east to west, reaching at one point, in Mt. Sarmiento, a height of 6,000 feet. Glaciers also descend to the sea on the Patagonian side in lat. 53°, at a point where the strait intersects the main chain of mountains which continues the Andes into Tierra del Fuego. Floating icebergs moreover abound off Cape Horn, where no less than 2,000 of them are sometimes counted in the spring season. There may, perhaps, be a still greater number of icebergs coming from the antarctic continent to that part of the ocean which surrounds S. Georgia; but the chief cause of the difference in climate between S. Georgia and Tierra del Fuego is probably the presence of the neighbouring low region of Patagonia, which causes in a great part of the year the winds from the north to be heated to an extent which the atmosphere can never acquire when passing over the sea which extends for twenty degrees north of S. Georgia.

Dr. Hector has remarked† that the north-west winds, when they blow for several days in succession from Australia to the southern island of New Zealand, are so hot and dry as to cause great floods by the sudden melting of the snow on the southern Alps of that island. He observes that if Australia were submerged, or if, at some former period, the sea covered a larger portion of the space now occupied by that continent, the New Zealand glaciers, which are now of considerable size, would have been more voluminous. I call the reader's attention to this fact, because, in speculating on a change of climate due to altered geographical conditions, it is too often

* Darwin's Journal, pp. 145, 209.

† Letter to Dr. J. Hooker, July 15, 1864.

assumed that the alteration must have taken place in the immediate region where the temperature has been modified.

Cold of the antarctic regions.—The cold of the antarctic regions was conjectured by Cook to be due to the existence of a large tract of land between the 70th degree of south latitude and the pole. The soundness of these and other speculations of that great navigator has since been singularly confirmed by the exploring expedition of Sir James Ross in 1841. He observed that the temperature south of the 60th degree of latitude seldom rose above 32° Fahr. During the two summer months (January and February) of the year 1841, the range of the thermometer was between 11° and 32° Fahr.; and scarcely once rose above the freezing point. He also ascertained that Victoria Land, extending from 71° to 79° south latitude, was skirted by a great barrier of ice in lat. 78° south, which rose only 150 feet above water, and he estimated its total thickness above and below water for about 600 miles to be not more than 1,000 feet, and here the height of the inland country ranges from 4,000 to 15,000 feet, as in Mt. Melbourne. This elevated region is opposite New Zealand and Tasmania; the whole of it was entirely covered with snow, except a narrow ring of black earth (scoriæ?) surrounding the huge crater of Mt. Erebus, an active volcano, which rises 12,400 feet above the level of the sea. Another part of the antarctic land, namely, that which approaches nearest to South America or Cape Horn, as, for example, Graham's Land, and Louis Philippe Land, reaches also a great altitude, namely, from 4,000 to 7,000 feet. The existence of such heights and of so vast an area of land—probably exceeding in dimensions the whole of Australia—may well account for the intense cold, which reaches to the 60th degree of latitude, and sometimes farther, towards the equator in the southern hemisphere. Captain Biscoe, in 1831-2, describes Graham's and Enderby's Lands, between latitudes 64° and 68° south, as presenting a most wintry aspect in summer, and as being nearly destitute of animal life. In corresponding latitudes of the northern hemisphere, owing chiefly to the influence of the Gulf-stream, we not only meet with herds of wild herbivorous animals, but with land (Lapland, Iceland,

and Greenland) which man himself inhabits, and where he has even built ports and inland villages.

The chief causes of the intense cold of high southern latitudes are twofold: first, the vast height and extent of the antarctic continent; and secondly, what is no less important, the almost entire absence of land in the South Temperate Zone, where its presence would warm the atmosphere. It may undoubtedly be said, that some part of the cold of south polar latitudes is due to the fact that their winters occur when the earth is at its greatest distance from the sun, and they are eight days longer than the winters of the northern hemisphere. That this cause is not without its effect in somewhat augmenting the quantity of antarctic ice, even with the present moderate excentricity of the earth's orbit, is most probable, and the amount might be increased if a still larger excentricity happened to concide with land of equal extent and elevation at the South Pole; but I shall endeavour to show in the next chapter, that the influence of excentricity will always be quite subordinate to geographical conditions in determining climate.

Effect of currents in equalising the temperature of high and low latitudes.—The dominant influence of the position of land in reference to north polar temperature is well shown by the fact that there is open sea nearer the pole than the northern extremity of Greenland. Antecedently to experience it might have been thought that the thickness of the ice would increase as it extended northwards; but Parry penetrated within about seven degrees, and Kane within five degrees, of the North Pole, and they both of them found open sea there, though they had reached a latitude so much higher than that in which the continent of Greenland is enveloped in a winding-sheet of perpetual snow and ice. From such facts the geologist may learn that, although in the Glacial epoch certain mountain-chains and adjoining low-lands may have been buried in temperate latitudes under a vast covering of ice, yet the waters of the ocean in much higher latitudes may not at the same period have been frozen. We are by no means called upon as geologists to embrace the opinion that an ice-cap once reached continuously from the pole to lat.

50°, still less to 40° in the temperate zone. It has long been a favourite opinion of northern voyagers that there is open sea during part of the year at the pole itself, and the observations of Eschricht and Reinhardt on the migrations of the Greenland whale are rather confirmatory of this idea. It appears that this northern whale, *Balœna Mysticetus*, is different from the whale called *B. Biscayensis*, a species now almost extirpated, and which once inhabited the British seas and the Bay of Biscay. In winter the Greenland whales accompany the ice when it floats farthest to the south in Baffin's Bay, but in the summer, when the ice is only to be found farther north, they migrate to parts of the sea nearer the pole, having been seen as far north as man has yet penetrated. Apparently they retreat to the polar sea, which cannot therefore be covered by a continuous sheet of ice, for in that case they would be suffocated, since they must occasionally come to the surface to breathe. They could, however, pass under considerable barriers of ice provided there were openings here and there; and so they may perhaps reach a more open sea near the pole, and find sustenance there during a day of more than five months' duration. This open sea is partly due to marine currents, by which the seas of higher and lower latitudes exchange their warm and cold waters. Of the equalising effect of such currents, as regards temperature, the Gulf-stream, which is chiefly caused, as we shall see in Chapter XX., by the trade winds, affords the best illustration. The waters of the Gulf of Mexico were calculated by Rennell to attain in summer a temperature of 86° Fahr., and more lately (in 1860) Prof. Bache estimated their temperature in June at 84° F., or 8° above that of the Atlantic in the same latitude. From this great reservoir or caldron of warm water, a constant current pours forth through the straits of Bahama at the rate of three or four miles an hour. According to Prof. Bache, it is twenty-five miles wide off Cape Florida, and its width increases to 127 miles off Sandy Hook, in lat. 40° 30′. Here it has a temperature of 80° F. for a depth of 15 fathoms, or 90 feet, a heat retained in one place as far down as 100 fathoms, while it continues to be 50° F. to a depth of 500 fathoms. Between

it and the land for the whole length of the eastern coast of the United States flows a cold current in an opposite direction, varying in width, but usually more than 200 miles wide, and having a temperature of only 40° F.;* so that here we see an active transference continually going on, of tropical heat to the poles and of polar cold to the tropics. Large icebergs coming from Baffin's Bay, having their lower parts immersed in the colder current, move southwards in spite of the opposite direction in which the superficial stream is running, and sometimes in direct opposition to a wind from the south. When the Gulf-stream skirts the great bank of Newfoundland, it still retains a temperature of 8° above that of the surrounding sea. In about seventy-eight days it reaches the Azores, after flowing nearly 3,000 geographical miles, and here it has, according to Dr. Petermann, a temperature of 81° F. From thence it extends its course a thousand miles farther, so as to reach the Bay of Biscay, still retaining an excess of 5° above the mean temperature of that sea. As it has been known to arrive there in the months of November and January, it must tend greatly to moderate the cold of winter in countries on the west of Europe. Passing on to the south-west of the Faroe islands, lat. 59° 35′, it still retains a heat of 51° F. at the surface, and 44° F. at a depth of 500 fathoms. Its further course has been minutely and carefully worked out by Dr. Petermann, in accordance with the results of all the exploring expeditions made up to the year 1870, by means of which he traces it to Nova Zembla with a heat of 36° 5′ F., and beyond this with a diminishing temperature into the Polar Basin.†

In the centre of the North Atlantic there is a large tract, between the parallels of 33° and 45° N. lat., which Rennell called the 'recipient of the Gulf water.' This mass of water is nearly stagnant, is warmer by 7° or 10° than the waters of the Atlantic, and may be compared to the fresh water of a river overflowing the heavier salt water of the sea. Rennell estimates the area of the 'recipient,' together with that

* Bache on the Gulf-stream.—American Journal of Science, 1860.

† Petermann, 'Der Golfstrom etc.,' Geographische Mittheilungen, 16. Band 1870, Nos. VI. and VII.

covered by the main current, as being 2,000 miles in length from E. to W., and 350 in breadth from N. to S., which, he remarks, is a larger area than that of the Mediterranean. The heat of this great body of water is kept up by the incessant and quick arrivals of fresh supplies of warm water from the south; and there can be no doubt that the general climate of parts of Europe and America is materially affected by this cause.

Principal J. D. Forbes calculated that the quantity of heat thrown into the Atlantic Ocean by the Gulf-stream on a winter's day would raise the temperature of the atmosphere which rests on France and Great Britain from the freezing point to summer's heat.* Scoresby remarked that the influence of the Gulf-stream extends to Spitzbergen, in 79° of N. latitude, and that the great glaciers which fill all the valleys of that island are cut off abruptly at the beach by the remnant of heat which the ocean still derives from this source.

In Baffin's Bay, on the west coast of Greenland, where the temperature of the sea is not mitigated by the same cause, the glaciers stretch out from the shore, and furnish repeated crops of mountainous masses of ice which float off into the ocean.† The number and dimensions of these bergs are prodigious. Capt. Sir John Ross saw several of them together in Baffin's Bay aground in water 1,500 feet deep! Many of them are driven down into Hudson's Bay, and, accumulating there, diffuse excessive cold over the neighbouring continent; so that Sir John Franklin reported, that at the mouth of Hayes' River, which lies in the same latitude as the north of Prussia or the south of Scotland, ice is found everywhere in digging wells, in summer, at the depth of four feet! It is a well-known fact that every four or five years a large number of icebergs, floating from Greenland, are stranded on the west coast of Iceland. The inhabitants are then aware that their crops of hay will fail, in consequence of fogs which are generated almost incessantly;

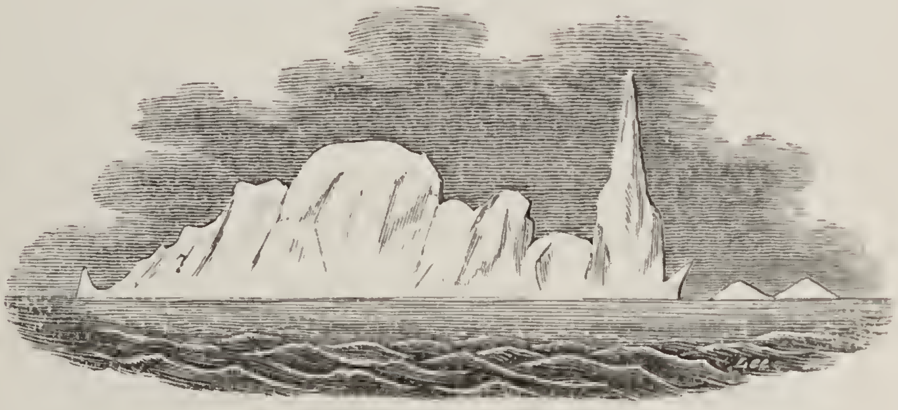
* Travels in Norway, p. 202.

† Scoresby's Arctic Regions, vol. i. p. 208.—Dr. Latta's Observations on the Glaciers of Spitzbergen, &c. Edin. New Phil. Journ. vol. iii. p. 97.

and the dearth of food is not confined to the land, for the temperature of the water is so changed that the fish entirely desert the coast.

In the northern hemisphere icebergs are constantly floated as far south in the Atlantic as the latitude of Madrid in Europe, or New York in America; the farthest point to which they are habitually carried lies to the S.E. of Newfoundland, in mid-ocean, and about half-way between the Azores and New York, in W. long. 45°. In the southern hemisphere they float to latitudes several degrees nearer the equator, as, for example, to points off the Cape of Good Hope between lat. 36° and 39°.* One of these (see fig. 10) was two miles in circumference, and 150 feet high, appear-

Fig. 10.



Iceberg seen off the Cape of Good Hope, April 1829.
Lat. 39° 13′ S. Long. 48° 46′ E.

ing like chalk when the sun was obscured, and having the lustre of refined sugar when the sun was shining on it. Others rose from 250 to 300 feet above the level of the sea, and were therefore of great volume below; since it is ascertained, by experiments on the buoyancy of ice floating in sea water, that for every cubic foot seen above there must at least be eight cubic feet below water, but it will depend on the shape of the berg and the position of its centre of gravity to what depth under water the mass will extend.† If ice islands from the north polar regions floated as far towards the equator as they do in the southern hemisphere, they might reach Cape St. Vincent, and there, being drawn by the current that always sets in from the Atlantic through

* On Icebergs in Low Latitudes, by Capt. Horsburgh, by whom the sketch was made. Phil. Trans. 1830.

† Rennell on Currents, p. 95.

the Straits of Gibraltar, be drifted into the Mediterranean, so that the serene sky of that delightful region might soon be deformed by clouds and mists.

The current which flows from the Indian Ocean through the Mozambique Channel, having a breadth of nearly a hundred miles and a velocity varying from two to four miles an hour, conveys warm water from a tropical to a temperate region. A current which flows in an opposite direction from Cape Horn northwards, along the west coast of South America, conveys colder water towards the tropics.

These oceanic rivers, as they have been called, exercise a great control over the temperature of the air in certain areas, causing deviations in the isothermal lines already alluded to (p. 241). Their course being to a great extent dependent on the position of the land, they add greatly to the influence which geographical conditions exert on the state of the climate at any given period. For instance, the waters in the Gulf of Mexico, which are driven westward and piled up by the continued influence of the east wind, are now deflected back by the Isthmus of Panama. But it is obvious that if this isthmus had no existence, these waters would flow on westward into the Pacific Ocean, instead of giving origin to the Gulf-stream. And as the watershed of the isthmus is in one part only 250 feet above the level of the sea, the breach here supposed is no extravagant speculation, but would be effected by a change of level not greater than we can show to have occurred in parts of the British isles since the commencement of the Glacial period.

Present proportion of polar land abnormal.—It has been well said, that the earth is covered by an ocean, in the midst of which are two great islands and many smaller ones; for the whole of the continents and islands occupy about two-sevenths, or a little more than one-fourth, of the whole superficies of the spheroid; the area of the sea to that of the land being as two and a half to one. Now, according to this analogy, we may fairly speculate on the probability that there would not be usually, at any given epoch of the past, more than about one-fourth dry land in a particular region; as, for example, near the poles, or between them and

the 60th parallels of N. and S. latitude. If, therefore, at present there should happen to be, in both these quarters of the globe, much *more* than this average proportion of land, if the land should actually be equal in area to the sea, and some of it in the arctic region 8,000 feet in height, and in the antarctic 15,000 feet, this alone affords ground for concluding that, in the present state of things, the mean heat of temperate and polar regions is far below that which in a more ordinary state of the earth's surface they would enjoy.

This presumption is greatly heightened when we discover that there is a deficiency of land between the tropics, where, in consequence of its being exposed to the direct, or nearly direct, rays of the sun, it would produce the greatest heat. For in the inter-tropical regions of the globe the sea is to the land as four to one, instead of two and a half to one. It is clear, therefore, that we have at present not only more than the usual degree of cold in the polar regions, but also less than the average quantity of heat within the tropics.

The reader will at once perceive that if it be a legitimate speculation on the part of the geologist to assume, that in past times the polar regions had usually within them the normal proportion of sea and land, of two and a half to one, between lat. 60° and the poles, instead of so abnormal a proportion as one to one, the climate of the temperate regions would be much warmer; and if there were periods when a deep ocean interspersed with a few islands prevailed at both poles (an event which would probably not be rare), there might be an entire absence of permanent snow and ice, even on the summit of the highest mountains. If such were the case, there would still be oceanic currents causing an exchange of temperature between high and low latitudes, but none of them would convey floating ice to lower the temperature of the sea between the arctic and antarctic circles and the tropics. In the present geographical state of the globe, the Alps, in latitude 46°, are covered with perpetual snow, and even under the equator itself a mountain 20,000 feet high has lately been discovered in Eastern Africa, which has its uppermost 4,000 feet always above the lowest

limit of snow;* but these mountainous heights would be very differently circumstanced if the aërial currents which circulate freely from polar to equatorial latitudes were not reduced in temperature by the wide extent of snow and ice now prevailing in both polar areas at all seasons of the year.

Succession of geographical changes revealed to us by geology.—To those whose attention has never been called to the former changes in the earth's surface which geology reveals to us, the position of land and sea appears fixed and stable. It may not seem to have undergone any material alterations since the earliest times of history; but when we enquire into the subject more closely, we become convinced that there is annually some small variation in the geography of the globe. In every century the land is in some parts raised, and in others depressed in level, and so likewise is the bed of the sea. By these and other ceaseless changes, the configuration of the earth's surface has been remodelled again and again, since it was the habitation of organic beings, and the bed of the ocean has been lifted up to the height of some of the loftiest mountains. The imagination is apt to take alarm when called upon to admit the formation of such irregularities in the crust of the earth, after it had once become the habitation of living creatures; but, if time be allowed, the operation need not subvert the ordinary repose of nature; and the result is in a general view insignificant, if we consider how slightly the highest mountain-chains cause our globe to differ from a perfect sphere. Chimborazo, though it rises to more than 21,000 feet above the sea, would be represented, on a globe of about six feet in diameter, by a grain of sand somewhat less in diameter than the letter o in this type.

The superficial inequalities of the earth, then, may be deemed minute in quantity, and their distribution at any particular epoch must be regarded in geology as temporary peculiarities, like the height and outline of the cone of

* Kellimandjaro, discovered by Dr. Redmann, in 1848, and measured in 1862 by Baron Von der Decken, who found it to be 20,065 feet high. Geograph. Journ. vols. xxxiv. xxxv.

Vesuvius in the interval between two eruptions. But although, in reference to the magnitude of the globe, the unevenness of the surface is so unimportant, it is on the position and direction of these small inequalities that the temperature of the atmosphere and the sea, and the circulation both of the aërial and oceanic currents, are mainly dependent.

Before I insist on the great fluctuations in temperature, to which the ever-varying form of the earth's crust must inevitably give rise, it will be desirable to say something of those geographical changes which are demonstrated by our geological records to have taken place. The reader has been in some degree prepared for the contemplation of such revolutions by what we have said in our retrospective survey of former states of the animate creation as bearing on climate. He has been told that even since the commencement of the Glacial period, when the living species of testacea and most of the existing animals and plants were in being, great changes in the height of European lands have occurred; what was formerly the bed of the sea having been raised, together with its marine shells, to elevations of 500 and even 1,400 feet, and corresponding subsidences, attended by the submergence of much ancient land, having taken place within an era so modern in the history of the earth. In one part of this Glacial period we find proofs that England and Ireland were united to each other, and to the continent, while at other times they were broken up into an archipelago of small islands; we also find that large parts of Northern Germany, and Russia, were beneath a sea often covered with floating ice; and that the Desert of the Sahara was under water between lats. 20° and 30° N., so that the eastern part of the Mediterranean communicated with that part of the ocean now bounded by the west coast of Africa. The Atlantic also penetrated far into what is now the basin of the St. Lawrence, and the White Mountains in New Hampshire constituted an archipelago. In short, a map of the northern hemisphere, even in glacial times, would bear but a distant resemblance to our present maps of the same region, and so far as we are acquainted with the geology of

equatorial countries, they have undergone an equal amount of alteration. This may be seen by anyone who will consult Darwin's map of coral reefs and active volcanos, which shows how many large areas have been the theatres, some of subsidence, others of elevation on a great scale, while the species of shells and corals of the Atlantic and Pacific have remained unchanged. The continent of South America, from lat. 34° S. to Patagonia, appears also to have been upraised throughout its entire width, since the beginning of the Post-Tertiary period. The geographical distribution of the quadrupeds, birds, and insects in the islands of the Malay Archipelago has enabled Mr. Wallace to demonstrate the former union of those islands with each other and with the mainland since the present species were in being. He has shown that the Indian fauna exhibits an abundance of species common to both sides of those straits, wherever the depth does not exceed 100 fathoms, whereas if the soundings are deeper, even though the separated lands be in sight of each other, the birds and mammalia are quite distinct.*

If we reflect on these facts, and consider what a brief space of time the Post-Tertiary era constitutes as compared to the whole of the Pliocene period, and if we then endeavour to form an idea of the duration of the antecedent Eocene and Miocene epochs by reference to the greater changes in organic life of which they afford evidence, we shall be prepared to find that a map representing the position of the land and sea in the earliest division of the Eocene period will be wholly unlike the picture which corresponding portions of the globe now present.

In the accompanying map (Plate I.) the proofs of submergence, during the period alluded to, in all the districts distinguished by ruled lines, are of a most unequivocal character; for the areas thus indicated are now covered by deposits containing the fossil remains of shells and other creatures which could only have lived in salt water. The most ancient part of the period referred to cannot be deemed very remote, considered geologically; because the deposits of the Paris

* Wallace, A., Physical Geography of Malay Archipelago, Journ. of Roy. Geograph. Soc. 1864.

Plate 1
MAP
Shewing the extent of Surface in
Europe
EOCENE PERIOD
Arctic Circle
White Sea
Gulf of Bothnia
G of Finland
Stockholm
St Petersburg
Copenhagen
Edinburgh
Dublin
London
Berlin
Dresden
Vienna
Moskow
R Volga
Madrid
Gulf of Lyons
CORSICA
SARDINIA
Gulf of Venice
Sea of Azof
B L A C K S E A
A F R I C A
Malta
OBSERVATIONS.

and London basins, and many other districts belonging to the older Tertiary epoch, are newer than the greater part of the sedimentary rocks, those commonly called Secondary and Primary (Mesozoic and Palæozoic), of which the crust of the globe is composed. Yet, notwithstanding the comparatively recent epoch to which this retrospect is carried, the variations in the distribution of land and sea depicted on the map form only a part of those which must have taken place during the same period. An approximation merely has been made to an estimate of the amount of *sea converted into land* in parts of Europe best known to geologists; but we cannot determine how much land has become sea during the same period; and there have been repeated interchanges of land and water in the same places, of which no account could be taken.*

I was anxious, even in the title of this map, to guard the reader against the supposition that it was intended to represent the state of the physical geography of part of Europe at any *one point of time*. The difficulty, or rather the impossibility, of restoring the geography of the globe as it may have existed at any former period, especially a remote one, consists in this, that we can only point out where part of the sea has been turned into land, and are almost always unable to determine what land may have become sea. All maps, therefore, pretending to represent the geography of remote geological epochs must be to a great extent ideal. The map under consideration is not a restoration of a former state of things at any particular moment of time, but a synoptical view of a certain amount of one kind of change (the conversion of sea into land) known to have been brought about within a given period.

The vertical movements to which the land is subject in certain regions, consist of the alternate subsidence and uprising of the surface; and such oscillations at successive

* In compiling this map I have availed myself of the government surveys of England, France, and Germany, and of the important map of Russia, published by Sir Roderick Murchison, M. de Verneuil, and Count Keyserling. M. de Verneuil's excellent map of Spain has also enabled me to extend the ruled lines over part of that country where before his survey no tertiary strata were supposed to exist.

periods, a great area may have been entirely covered with marine deposits, although the whole may never have been beneath the waters at one time; nay, even though the relative proportion of land and sea may have continued unaltered throughout the whole period. I believe, however, that since the commencement of the Tertiary period the dry land in the northern hemisphere has been continually on the increase, both because it is now greatly in excess beyond the average proportion which land bears to water on the globe generally, and because a comparison of the Secondary and Tertiary strata affords indications of a passage from the condition of an ocean interspersed with islands to that of a large continent.

But supposing it were possible to represent all the vicissitudes in the distribution of land and sea that have occurred during the Tertiary period, and to exhibit not only the actual existence of land where there was once sea, but also the extent of surface now submerged which may once have been land, the map would still fail to express all the important revolutions in physical geography which have taken place within the epoch under consideration. For the oscillations of level, as was before stated, have not merely been such as to lift up the land from below the water, but in some cases to occasion an additional rise of tracts which had already emerged. Thus the Alps have acquired 4,000, and even in some places more than 10,000 feet of their present altitude since the commencement of the Eocene period; and the Pyrenees have attained their present height, which in Mont Perdu exceeds 11,000 feet, since the deposition of the nummulitic or Eocene division of the Tertiary series. Some of the Tertiary strata at the base of the chain are only a few hundred feet above the sea, and retain a horizontal position, without partaking in general in the disturbances to which the older series has been subjected; so that the great barrier between France and Spain was almost entirely upheaved in the interval between the deposition of certain groups of Tertiary strata.

On the other hand, some mountain-chains may have been lowered during the same lapse of ages, in an equal degree,

and shoals have probably been converted into deep abysses, as seems decidedly to have taken place in the Mediterranean. Geologists are now agreed that the limestone and associated strata called nummulitic belong to the Eocene group; as these rocks enter into the structure of some of the most lofty and disturbed parts of the Alps, Apennines, Carpathians, Pyrenees, and other mountain-chains, and form many of the elevated lands of Africa and Asia, their position almost implies the ubiquity of the Eocene ocean in regions which are now dry land, not, indeed, by the simultaneous, but by the successive, occupancy of the whole ground by its waters.*

Antiquity of existing continents.—It is perfectly consistent with the preceding observations to affirm that our present continents are extremely ancient. They have all of them, it is true, undergone many minor modifications in their form even in Post-Tertiary times, some parts of them having been submerged, and others so much raised as to have been united with what are now islands lying at some distance from them. But the principal masses of land have continued so long above water, that each of them is now tenanted by a distinct set of animals and plants. More than this: we find, when we examine the fossil remains of land quadrupeds of Pliocene date proper to each continent, that although they may be of extinct species, they are allied in structure to the living mammalia of the same region. Extinct species of kangaroo, for example, and of other marsupials, preceded the living marsupials on the Australian continent. In like manner, species of elephant and rhinoceros, and of catarrhine monkeys, of forms no longer in existence, inhabited India in Miocene and Pliocene times, before the living representatives of the same genera and families were in being; while, in the New World, the platyrrhine quadrumana and the sloths, armadillos, and other South American forms belonging to an extinct fauna, flourished in times immediately antecedent to those of the recent mammalia of the same continent.

* See Sir R. Murchison's Paper on the Alps, Quart. Journn. Geol. Soc. vol. v.; and my Anniversary Address for 1850, ibid. vol. vi.

The complete dissimilarity, also, of the marine fauna on the opposite sides of several continents attests the permanence of the great barriers of land, which have, from a remote age, prevented the migration of fish, mollusca, and other aquatic tribes from one sea to the other. But the distinctness of these marine provinces does not go back to the Lower Miocene period; and even when we carry back our retrospect to the Upper Miocene, we find evidence that the mollusca and corals of the Atlantic and Pacific Oceans by no means belonged to such distinct assemblages of species as they do now. There must have been up to that time a communication through the Isthmus of Panama, as is proved by the study of the corals and marine shells of the West Indian islands.* If we go back still further—to the terrestrial plants and animals of the Eocene period—we find such a mixture of forms now having their nearest living allies in the most distant parts of the globe, that we cannot doubt that the distribution of land and sea bore scarcely any resemblance to that now established, while in regard to the ocean of that era, what we have said (p. 207) of marine strata of the Eocene period shows how many mountain-chains forming the backbones of the present continents were submerged when the marine fauna of that period were already in existence.

Continents therefore, although permanent for whole geological epochs, shift their positions entirely in the course of ages. The great slowness with which the change is always brought about results from a peculiarity in the external configuration of the earth's crust, which I shall point out in the sequel of this chapter (see p. 268).

Both in the eastern and western hemispheres north of the equator, when we carry our retrospect beyond the limits of the tertiary rocks, and pass on to the antecedent cretaceous formations, we find abundant proofs of an open sea in regions which are now continental. In the oldest part of this period, in the south of England, we find in the Wealden strata the memorials of the delta of a large river, implying a contour

* See Papers by John Carrick Moore, Esq., and Dr. Duncan, referred to in Elements of Geology, 6th edition, 1865, p. 271.

of land and sea which has no reconcilable relation to existing geographical conditions; and it is worthy of note that, although the foundations of this delta sank during the accumulation of the fluviatile strata as much as 1,000 or sometimes 1,500 ft., yet there continued to be land in the neighbourhood in the south-east of England; which can scarcely be explained except by supposing that an upward movement was taking place in the vicinity of a downward one, or that adjoining parts of the surface were moving slowly in opposite directions.

The frequent unconformability of strata of different ages is a proof that, if we had a series of maps, in which restorations of the physical geography of thirty or more periods were depicted, they would probably bear no more resemblance to each other or to the actual position of land and sea than does the map of one hemisphere at present bear to that of the other.

The height to which ammonites, shells, and corals have been traced in the Alps, Andes, and Himalaya is sufficient to show that the materials of all those chains were elaborated under water, and some of them in seas of no slight depth. Beds of coal, in the ancient carboniferous formation, attest the former existence of land, since the plants from which they are derived must have grown on low swamps covered with forests. The sand and shales which over- and under-lie them must have been formed at the termination of large hydrographical basins, each drained by a great river and its tributaries; and the accumulation of sediment bears testimony to contemporaneous denudation on a large scale, and, consequently, to an area of land probably containing within it one or more mountain-chains.

In the case of the great Ohio or Appalachian coal-field, the largest in the world, it seems clear that the uplands drained by one or more great rivers were chiefly to the eastward, or occupied a space now covered by the Atlantic Ocean, for the mechanical deposits of mud and sand increase greatly in thickness and coarseness of material as we approach the eastern borders of the coal-field, or the south-east flanks of the Alleghany Mountains, near Philadelphia—in other words,

as we get nearer to the Atlantic. In that region numerous beds of pebbles, often of the size of a hen's egg, are seen to alternate with beds of pure coal.

It has also been observed, in reference not only to the Carboniferous but to the antecedent Devonian and Silurian rocks of North America, that all the mechanical deposits as we travel from the Atlantic border to the Mississippi diminish constantly in thickness, while the limestones and rocks of organic origin, or open-sea deposits, with corals and encrinites, increase and replace the others.

But the American coal-fields are all comprised within the 30th and 50th degrees of north latitude; and there is no reason to presume that the lands at the borders of which they originated ever penetrated so far, or in such masses, into the colder and arctic regions, as to generate a cold climate. One of the members of the Carboniferous group, the mountain limestone, was of marine origin, and its occupancy of large areas in Europe and the United States, and in parts of North America bordering the Arctic Sea, makes it quite conceivable that there may have been such a condition of things at the period of the coal as might give rise to a general warmth and uniformity of climate throughout the globe.

The Silurian strata now constituting parts of many upland or mountainous regions in Europe and America were formed for the most part in deep seas far from land, which may account for their being almost entirely destitute of the remains of terrestrial plants.

Present unequal distribution of land and sea.—Without dwelling longer on the proofs with which geology supplies us of former changes in physical geography, it is not too much to say that every spot which is now dry land has been sea at some former period, and every part of the space now covered by the deepest ocean has been land. The present distribution of land and water encourages us to believe that almost every conceivable transformation in the external form of the earth's crust may have been gone through. In one epoch the land may have been chiefly equatorial, in another for the most part polar and circumpolar. At one period most of it may have been north of the line, in another south of it; or

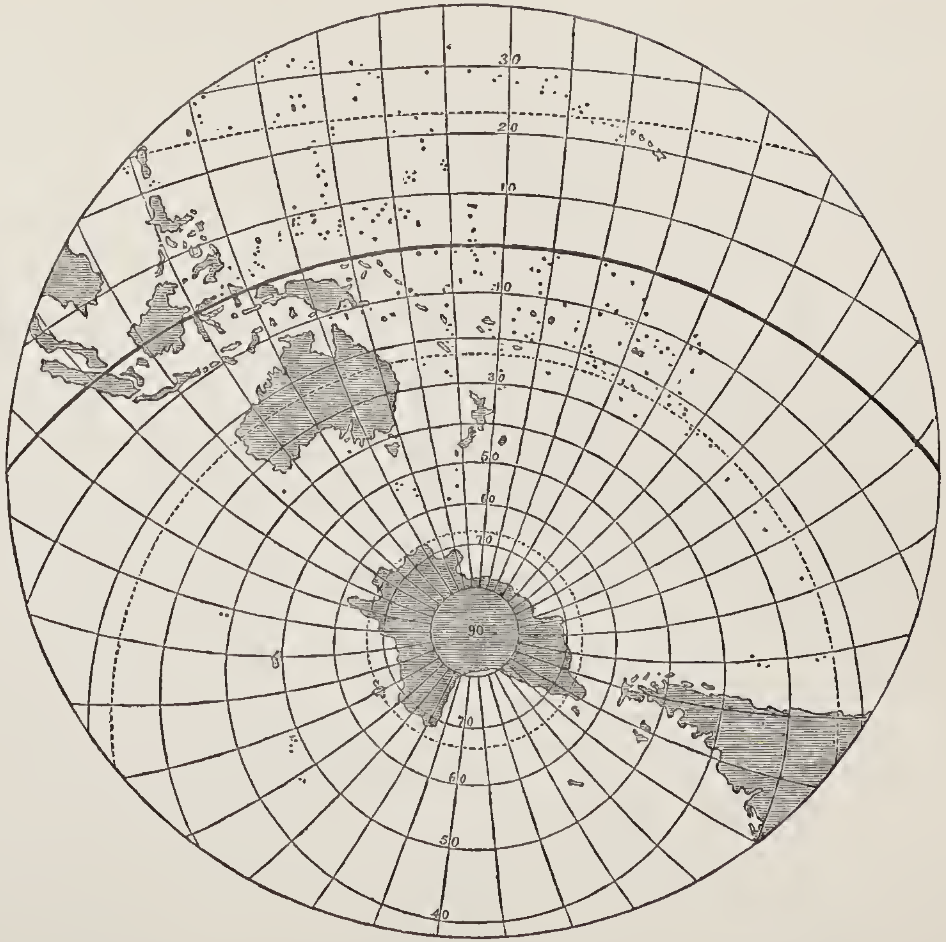
at one time all in the west, at another the whole of it in the east. In illustration of this point, it may be well to state that there is now just twice as much land in the eastern as there is in the western hemisphere; and even assuming the existence of an antarctic continent, more than twice as much land north of the equator as south of it. But what is most singular, as showing the capricious distribution of the land in the present state of the earth's crust, we find it possible so to divide the globe into two equal parts, that one hemisphere shall contain as much land as water, while the other is so oceanic that the sea is to the land very nearly as 8 to 1.* This is shown by projecting the hemispheres on the plane of the horizon of a point in lat. 52° N. and in long. 6° W. of Greenwich (see p. 262). The point alluded to is situated in St. George's Channel, about midway between Pembroke and Wexford, and the eye of the observer is supposed to be so placed above it as to see from thence one-half of the globe. In such a position he would behold at one view the greatest possible quantity of land, or, if transferred to the opposite or antipodal point, the greatest possible quantity of water.

In previous editions I used, in illustration of the same subject, a map projected for me by the late Mr. James Gardner on the horizon of London, for he regarded that metropolis as the centre of the Land hemisphere. The maps now presented to the reader have been executed by Mr. Trelawny Saunders, who has so divided the globe as to add to the Land hemisphere part of S. America, including a portion of the Peruvian coast, while an equivalent area of the China Sea is transferred to the Water hemisphere. Intimately connected with the excess of land in the one hemisphere as compared to that in the other is the fact that, even allowing for the antarctic continent as expressed in the map, only one-thirteenth part of the dry land has any land directly opposite to it. Thus, in fig. 11 the land shaded black between the China Sea and Lake Baikal answers to that portion of S. America and Tierra del Fuego which is antipodal to it. Farther north, a part of the continent of Asia,

* The exact proportion of land to sea, as calculated by Mr. Saunders, is 1 to 1·106 in the Land Hemisphere, and 1 to 7·988 in the Water Hemisphere.

Fig. 11.

Fig. 12.



MAP SHOWING THE PRESENT UNEQUAL DISTRIBUTION OF LAND AND WATER ON THE SURFACE OF THE GLOBE.

Fig. 11. Here a point in St. George's Channel, midway between Pembroke and Wexford, is taken as a centre, and we behold the greatest quantity of land existing in one hemisphere.

Fig. 12. Here the centre is the antipodal point to that taken in Fig. 11, and we see the greatest quantity of water existing in one hemisphere.

extending along the arctic sea, as well as a large tract of Greenland and other arctic lands shaded in the same manner, are antipodal to the antarctic continent. The dark spots in South America represent tracts antipodal to Java, Borneo, Celebes and the Philippines, a part of Sumatra, and the Malay peninsula. The specks in Africa bear a similar relation to the islands in the Pacific Ocean, and the dark patches in Spain and Morocco mark those countries as partially antipodal to New Zealand.

The limits of the supposed antarctic continent have been drawn with reference to the known position of Victoria, Wilkes', Enderby's, and Graham's Lands, and the points where Ross, Weddell, and other navigators were stopped by the ice; but in order not to exaggerate the proportion of dry land in the unexplored area, I have assumed one-eighth of it to be sea. This reduction has been made by extending the basin of the ocean somewhat nearer the pole than the points to which our navigators have yet penetrated, both between Graham's and Enderby's Lands and between the latter and Termination Land, in the former of which regions the ships were usually stopped by pack-ice before reaching the 70th and in the other the 65th degree of latitude. On the other hand, I have thought it safer not to represent all the unexplored area at the N. Pole as sea; and have therefore given one-eighth of it as land, which has been done by introducing several supposed islands in the open sea said to exist off the Russian coast, and off the N.W. of Greenland.

Former geographical changes which may have caused the fluctuations in climate revealed to us by geology.—Having now shown the reader that there have been endless changes in the form of the earth's crust in geological times, whereby the position as well as the height and depth of the land and sea has been made to vary incessantly, and that on these geographical conditions the temperature of the atmosphere and of the ocean in any given region and at any given period must mainly depend, I shall next proceed to speculate on the nature of the changes which, if assumed, might account for the leading facts revealed to us by geology, as explained in the last two chapters.

In order that our speculations may be confined within the strict limits of analogy, I shall assume, 1st, That the proportion of dry land to sea continues always the same. 2ndly, That the volume of the land rising above the level of the sea is a constant quantity; and not only that its mean, but that its extreme height, is liable only to trifling variations. 3rdly, That on the whole, and in spite of local changes, both the mean and extreme depth of the sea are invariable; and 4thly, That the grouping together of the land in continents is a necessary part of the economy of nature. I think it consistent with due caution to make this last assumption, because it is possible that the laws which govern the subterranean forces, and which act simultaneously along certain lines, cannot but produce at every epoch, continuous mountain-chains; so that the subdivision of the whole land into innumerable islands may be precluded.

If it be objected, that the maximum of elevation of land and depth of sea are probably not constant, nor the gathering together of all the land in certain parts, nor even perhaps the relative extent of land and water, I reply, that the arguments about to be adduced will be strengthened if, in these peculiarities of the surface, there be considerable deviations from the present type. If, for example, all other circumstances being the same, the land is at one time more divided into islands than at another, a greater uniformity of climate might be produced, the mean temperature remaining unaltered; or if, at another era, there were mountains higher than the Himalaya, these, more especially when placed in high latitudes, would cause a greater excess of cold. Or, if we suppose that at certain periods no chain of hills in the world rose beyond the height of 10,000 feet, a greater heat might then have prevailed than is compatible with the existence of mountains thrice that elevation.

Since I first proposed in 1830 to account for the more genial climates of former times, by showing that there is now an excess of land in polar regions, Mr. Hopkins made some important calculations to prove that, by reasoning on data, supplied by the isothermal maps of Dove, we may infer that a great alteration in climate would be brought about

in the northern hemisphere by what every geologist must regard as slight alterations in geography. If, said he, we assume; 1st, the diversion of the Gulf-stream from its present northerly course; 2ndly, the depression of the existing land of Northern and Western Europe to the amount of no more than 500 feet; and 3rdly, a cold current from the North, sweeping over this submerged area, the effect would be, that both on Snowdon and the lower mountains of the West of Ireland the snow-line would descend to within 1,000 feet of the sea-level, and glaciers reach the sea.* Now everyone who is aware of the rising and sinking of land, of which we have proofs since the present species of animals and plants were in existence, or since the commencement of the Glacial epoch, will be prepared to concede that, without violating probability, we may imagine far more important changes to have occurred since the older Pliocene period than those above suggested. Even if we admit that the Glacial period began as far back as the close of the Newer Pliocene era, when perhaps 5 in 100 of the mollusca were of different species from those now living, we might still fairly speculate on the lapse of a period more than ten times as long since the older Pliocene deposits were formed, for in these more than half the shells belong to extinct species. We might reckon on a tenfold greater amount of geographical change as having occurred in an interval sufficient to allow of fluctuations in organic life on so much grander a scale. Even if changes in the position of land and sea are brought about as slowly as those now in progress, so as to be quite insensible to ordinary observation, we may still be prepared to believe that when we go back to the older Pliocene period, land between the arctic and antarctic circles and the pole may have been so much less in quantity as compared to what it now is, that, instead of being equal in area to the sea, it may only have been in the proportion of about 1 to $2\frac{1}{2}$. But such a reduction of the quantity of land in high latitudes would be accompanied by an equivalent increase of land in temperate or tropical regions, unless we suppose the general surface of the earth's crust to have been less irregular than it is now—

* Quarterly Journ. Geol. Soc. 1852.

an hypothesis which we are not entitled to make. Consequently, whatever is lost to polar areas, where land gives rise to an augmentation of cold, would be gained in those lower latitudes, where it causes an increase of warmth. Therefore a more normal state of geography, or one in which the polar, temperate, and equatorial regions would each contain more nearly than they do now a proportion of one part land to two and a half parts sea, would bring back those genial climates which generally obtained in the past history of the world. It may perhaps be thought that the proofs lately brought to light of a rich vegetation having existed in Tertiary and even Cretaceous times within 10° of the pole, attest a greater extent of land in very high latitudes than is consistent with the theory above proposed. But the reader must bear in mind that we are always assuming that rather more than a fourth of the arctic area may have consisted of land, and this would be quite sufficient to produce the fossil plants hitherto discovered. It should also be remembered that we must not take for granted that the land from which arctic Tertiary strata derived their fossil plants was all above water at the same time, since even if it belongs to one era, such as the Miocene, there may have been great oscillations of level and conversion of sea into land and land into sea during the successive phases of the Miocene vegetation.

The accompanying map (fig. 13) may help the reader to imagine what would be the amount of change, if the geography of the globe were altered from its present exceptional state to what I consider a more normal condition of things. In this ideal map the excess of land is removed from the arctic and antarctic zones, and transferred to the tropical zone, which last, after this accession, contains only its normal quantity of land, or a proportion to the water of about 1 to $2\frac{1}{2}$. The land thus shifted from the poles has not been placed at random in the tropics, but has been made to fill those oceanic spaces which are supposed to have been above water in Post-Tertiary, or at least, in Newer Pliocene times, in accordance with Darwin's map of coral atolls. No doubt during such an amount of transposition of sea and

Fig. 13.

Ideal Map, in which the north and south polar lands are reduced to a normal quantity—1 land to $2\frac{1}{2}$ sea; the present excess being shifted to areas of modern subsidence between the Tropics. (See p. 266.)

land in the polar and equatorial zones, there would be a corresponding amount of change in the outline of continents and islands in other regions; but those changes, if taking place within the same zone, might have but slight effect on the general climate of the globe or the average temperature of the atmosphere. So long as the conversion of sea into land or land into sea does not cause any alteration in the proportions of land to water in the same zones, a vast amount of fluctuation may take place without those zones being rendered warmer or colder. Even if the land and sea in the eastern and western hemispheres were to change places, this need not affect the general temperature of the earth's surface, although the transfer of an equal volume of land from the torrid zone to the arctic or antarctic regions would cause a prodigious refrigeration in all latitudes. I have therefore left the land and sea as they now are, that those variations in geography which would affect climate may be more easily recognised. In this same map it will be seen that the diminution of arctic and antarctic land would enable oceanic currents to flow more freely from high to low, and from low to high latitudes, so that there might always be much open sea at the poles. But I have not attempted to deal in this map with submarine geography or the shape of the sea-bottom, which must nevertheless often affect the course and direction of ocean currents, as well as that slow movement by which an interchange of waters of different temperature may be effected between the equatorial and polar seas.

Great depth of the sea as compared to the mean height of the land connected with the slowness of climatal changes.—I shall conclude this chapter by observing that if at any former period the climate of the globe was much warmer or colder than it is now, it would have a tendency to retain that higher or lower temperature for a succession of geological epochs. That tendency would usually be in favour of warmer climates, because these would be consistent with a normal state of geography; but if once abnormal conditions like the present prevailed, they would be persistent for an indefinite lapse of ages. The slowness of climatal change here alluded to would arise from the great depth of the sea as compared

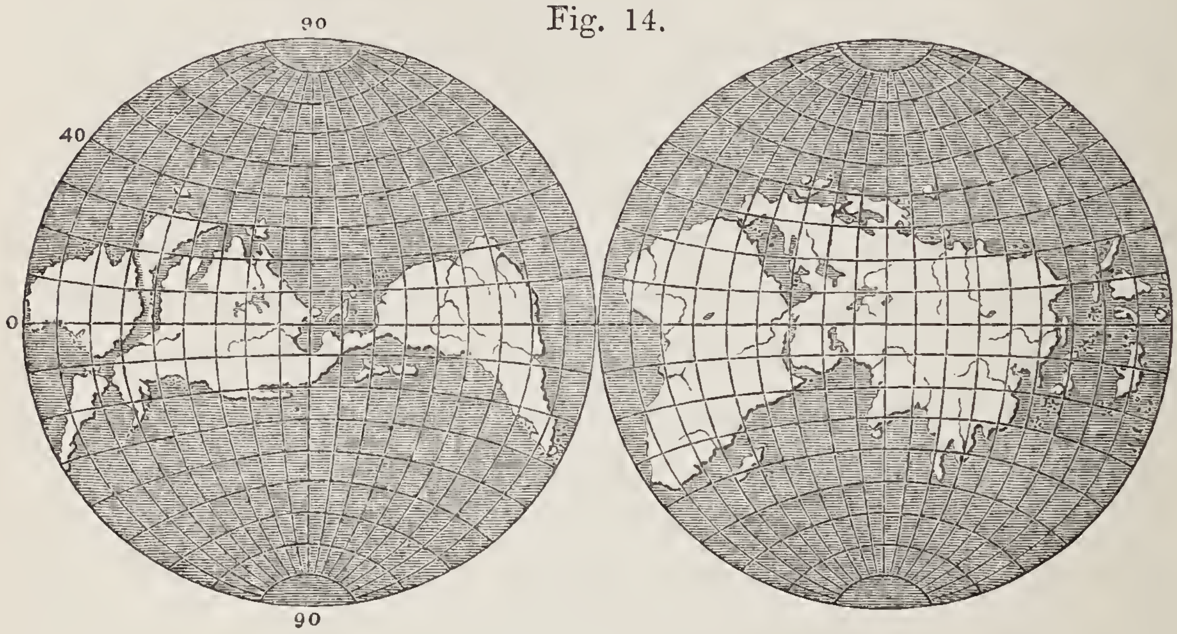
to the height of the land, and the consequent lapse of time required to alter the position of continents and great oceanic basins.

To one who contemplates the vast amount of geographical change which has occurred in Post-Tertiary, and still more in Pliocene and Miocene times, it might at first sight appear that in the course of such a period as might correspond with the disappearance of one set of organic beings and the coming in of another, there would be an almost unlimited revolution in the outward form of the earth's crust. But such an opinion would not be in harmony with the facts which have come to our knowledge of late years in regard to the average height of the continents as contrasted with the enormous depth of the sea, both as inferred theoretically from observations on the tidal wave, and proved practically by deep-sea soundings. These have been very generally supposed to demonstrate that the average depth of the sea is 15,000 feet; while the mean height of the land is only 1,000 feet. Even if this estimate of the average depth of the ocean be an exaggeration, as some suspect, yet its excess over the height of the land is indisputable, for inequalities amounting to three or five miles, which on the land are so exceptional as to be confined to a few peaks and narrow ridges, occur in the abysses of the ocean continuously over wide areas. The effect therefore of vertical movements, equalling 1,000 feet in both directions, upward and downward, is to cause a vast transposition of land and sea in those areas which are now continental, and adjoining to which there is much sea not exceeding 1,000 feet in depth. But movements of equal amount would have no tendency to produce a sensible alteration in the Atlantic or Pacific Oceans, or to cause the oceanic and continental areas to change places. Depressions of 1,000 feet would submerge large areas of the existing land, but fifteen times as much movement would be required to convert such land into an ocean of average depth, or to cause an ocean three miles deep to replace any one of the existing continents. It is quite essential to bear in mind this remarkable feature in the physical geography of the earth, when we are speculating on the cause of the permanence of a particular

climate, or distribution of heat or cold during a series of epochs. According to the doctrine of chances, it would not often happen that even one of the polar regions would con-

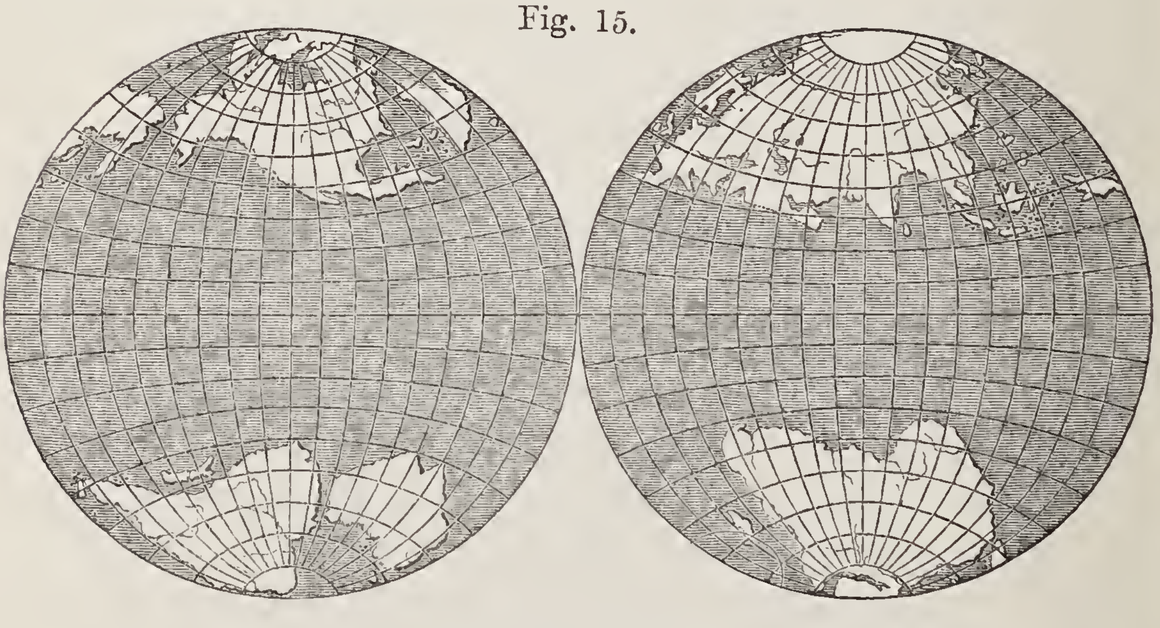
MAPS showing the position of LAND and SEA which might produce the Extremes of HEAT and COLD in the Climates of the GLOBE.

Fig. 14.



Extreme of Heat.

Fig. 15.



Extreme of Cold.

OBSERVATIONS.—These maps are intended to show that continents and islands having the same shape and relative dimensions as those now existing, might be placed so as to occupy either the equatorial or polar regions.

In fig. 14, scarcely any of the land extends from the Equator towards the poles beyond the 30th parallel of latitude; and in fig. 15, a very small proportion of it extends from the poles towards the Equator beyond the 40th parallel of latitude.

tain so much land as each of them does at present, but great indeed would be the chances against the simultaneous preponderance of such an abnormal quantity of land, both in arctic and antarctic latitudes.

The annexed maps will enable the reader to understand the manner in which land, having the same proportion to the sea of 1 to $2\frac{1}{2}$ as it now has, might be collected together in equatorial or polar regions. Such extremes may never have occurred, but we may safely conclude that there may sometimes have been an approximation to them in the course of those ages to which our geological records refer. A glance at these maps will make it evident that in the present state of the globe we are much nearer to the winter than to the summer of the 'Annus Magnus,' or great cycle of terrestrial climate.

CHAPTER XIII.

VICISSITUDES OF CLIMATE, HOW FAR INFLUENCED BY ASTRONOMICAL CHANGES.

THE PRECESSION OF THE EQUINOXES, AND VARIATIONS IN THE EXCENTRICITY OF THE EARTH'S ORBIT, CONSIDERED AS AFFECTING CLIMATE—SIR JOHN HERSCHEL'S VIEWS UPON THIS SUBJECT—LATER THEORIES AS TO THE EFFECT OF ASTRONOMICAL CAUSES—CLIMATES OF THE SUCCESSIVE PHASES OF PRECESSION—PREDOMINATING EFFECT OF GEOGRAPHICAL CAUSES ON THE PRESENT CLIMATE OF THE EARTH—HOW FAR WE MAY SPECULATE ON A PROBABLE DATE FOR THE GLACIAL PERIOD—EVAPORATION OF ICE AND SNOW IN A DRY WAY—RADIATION OF HEAT IMPEDED BY A COVERING OF SNOW—ABSENCE OF RECURRENT GLACIAL PERIODS IN THE EARLIER FORMATIONS—VARIATION IN THE OBLIQUITY OF THE ECLIPTIC—SUPPOSED VARIATIONS IN THE TEMPERATURE OF SPACE—SUPPOSED DIMINUTION OF THE EARTH'S PRIMITIVE HEAT.

IN the last chapter we were chiefly occupied in considering how far changes in physical geography or in the position of land and sea may account for those variations of climate to which geology bears testimony. I endeavoured to show that this class of causes must always have exerted a dominant influence; and we may now consider how far those variations in the relative position of our planet to the sun and the other heavenly bodies which astronomy reveals to us, may have co-operated with geographical conditions in bringing about fluctuations of temperature on the globe in former ages.

The influence of astronomical changes on climate considered by Sir J. Herschel.—Sir John Herschel in 1832* entertained the question whether there are any astronomical causes which might offer a possible explanation of the difference between the actual temperature of the earth's surface and the climates which appear formerly to have prevailed. 'Geometers,' he observed, 'had demonstrated the absolute invariability of the earth's mean distance from the sun, whence it would seem to follow that the mean annual supply of light

* Trans. Geol. Soc. 2nd series, vol. iii.

and heat would be alike invariable. This, however, is not exactly true: the total quantity of heat received in one revolution is inversely proportional to the minor axis;' still, as the extreme amount of difference in the quantity of heat annually received, owing to such change in the minor axis, can never by possibility exceed the whole supply in a ratio of more than 1,003 to 1,000, it may, he says, be neglected in our geological speculations.

But there is another way in which changes in the excentricity of the orbit affect climate. Climate depends, not merely on the absolute amount of heat, but on the manner in which it is distributed through different parts of the year, especially in the polar and circumpolar zones of the earth. There are in fact three astronomical causes which by their combination with each other and with varying geographical conditions may exert a sensible influence on the earth's climate. These are the phenomena known as the excentricity of the earth's orbit, the precession of the equinoxes, and the revolution of the apsides.

It is well known that the orbit of our earth round the sun is not circular, but elliptical, the sun occupying one of the foci of the ellipse (see figs. 16 to 19, p. 276), so that the earth in its yearly course now approaches in December, or our northern winter, three millions of miles nearer the sun than it does in June (see fig. 16), the mean distance of the earth from the sun being 91,400,000 miles.* The extreme point of approach is called *perihelion*, the extreme point of distance *aphelion*.

The difference of three millions of miles which now expresses the excentricity of the earth's orbit is not constant: at present the orbit is becoming every year more circular, at a very slow and somewhat irregular rate, and it will become in 23,980 years after A.D. 1800 nearly as circular as it can ever be, or will approach a minimum excentricity, when the difference between perihelion and aphelion will only slightly exceed half a million of miles, or one-sixth of the present; after this the excentricity will again increase at the same slow rate. The movement will not be constant in one direction, but will

* Herschel's Astronomy, art. 368.

vary within fixed limits, the extreme range of difference which it can ever attain amounting to fourteen millions of miles, as was shown by Lagrange towards the end of the last century, and more exactly by Leverrier in 1839. The cause of these perturbations is the attraction of the nearest and largest planets, Jupiter and Saturn playing the principal part, and Venus and Mars also exerting a sensible influence.

Whatever be the ellipticity of the earth's orbit, says Sir J. Herschel, the two hemispheres must receive equal absolute quantities of light and heat per annum, the proximity of the sun in perigee or its distance in apogee exactly compensating the effect of its swifter or slower motion.* But the same writer, in 1858, alluding to some speculations of Reynauld, speaks of the marked effects on climate which great variations in excentricity might produce, causing the characters of the seasons in the two hemispheres to be strongly contrasted. So long as the position of the earth's perihelion remained the same as now 'we should have in the northern a short but very mild winter, with a long but very cool summer —i.e., an approach to perpetual spring; while the southern hemisphere would be inconvenienced, and might be rendered uninhabitable by the fierce extremes caused by concentrating half the annual supply of heat into a summer of very short duration, and spreading the other half over a long dreary winter, sharpened to an intolerable intensity of frost when at its climax, by the much greater remoteness of the sun;'† and he goes on to observe that, in consequence of the precession of the equinoxes, combined with the secular movement of the aphelion, the state of the northern and southern hemispheres here alluded to, would in the course of about 11,000 years be reversed, and as such alternations of climate must in the immense periods of the past which the geologist contemplates have happened, not once only, but

* This follows, observes Herschel, from a very simple theorem, which may be thus stated: 'The amount of heat received by the earth from the sun, while describing any part of its orbit, is proportional to the angle described round the sun's centre.' So that if the orbit be divided into two portions by a line drawn *in any direction* through the sun's centre, the heat received in describing the two unequal segments of the ellipse so produced will be equal.—Geol. Trans. vol. iii. part ii. p. 298; second series.

† Herschel's Astronomy, art. 368 c.

thousand of times, 'it is not impossible,' he adds, 'that some of the indications of widely different climates in former times may be referable, in part at least, to this cause.'

The precession of the equinoxes here alluded to is due, as is well known, to the attraction of the sun and moon on the protuberant matter at the earth's equator, and its effect is to cause the different seasons of the northern and southern hemisphere to coincide successively with all the points through which the earth passes in its orbit round the sun. This great cycle of change would be gone through in 25,868 years were it not shortened by being combined with another movement called the revolution of the apsides, or, in the passage above cited from Herschel, the 'motion of the aphelion.' This last consists of a gradual change in the direction of the major axis of the earth's orbit, due to the same disturbing forces which cause the ellipticity of the orbit to vary, namely, the attraction of the larger and nearer planets. The result of the combination of these two causes of perturbation is that in about 10,500 years the present astronomical state of things will be reversed, and in 21,000 years the seasons will have made a complete revolution, so as again to coincide with the same point in the orbit as at present. For example, our winter in the northern hemisphere occurs at present in perihelion (see fig. 16), our pole being turned away from the sun when the earth is nearest to the sun. But in consequence of the precession of the equinoxes and the revolution of the apsides, our winter will have passed in 5,250 years through about one quarter of the orbit, and will occur at *a*, fig. 17. In another 5,250 years it will have reached aphelion (see fig. 18), and our long northern winter nights will coincide with the greatest distance of the earth from the sun. In another 5,250 years it will have reached *a*, fig. 19; and, finally, 21,000 years from the time at which it started, the earth will again arrive at that point in which our winter and the antarctic summer coincide with perihelion (fig. 16).

If the orbit were circular, and our planet always equidistant from the sun, this precession of the equinoxes would have no effect upon climate; but the orbit being elliptical, it

is easy to see that, astronomically speaking, the northern winter in perihelion, as shown in fig. 16, ought to be less rigorous than winter of the same hemisphere in aphelion, as

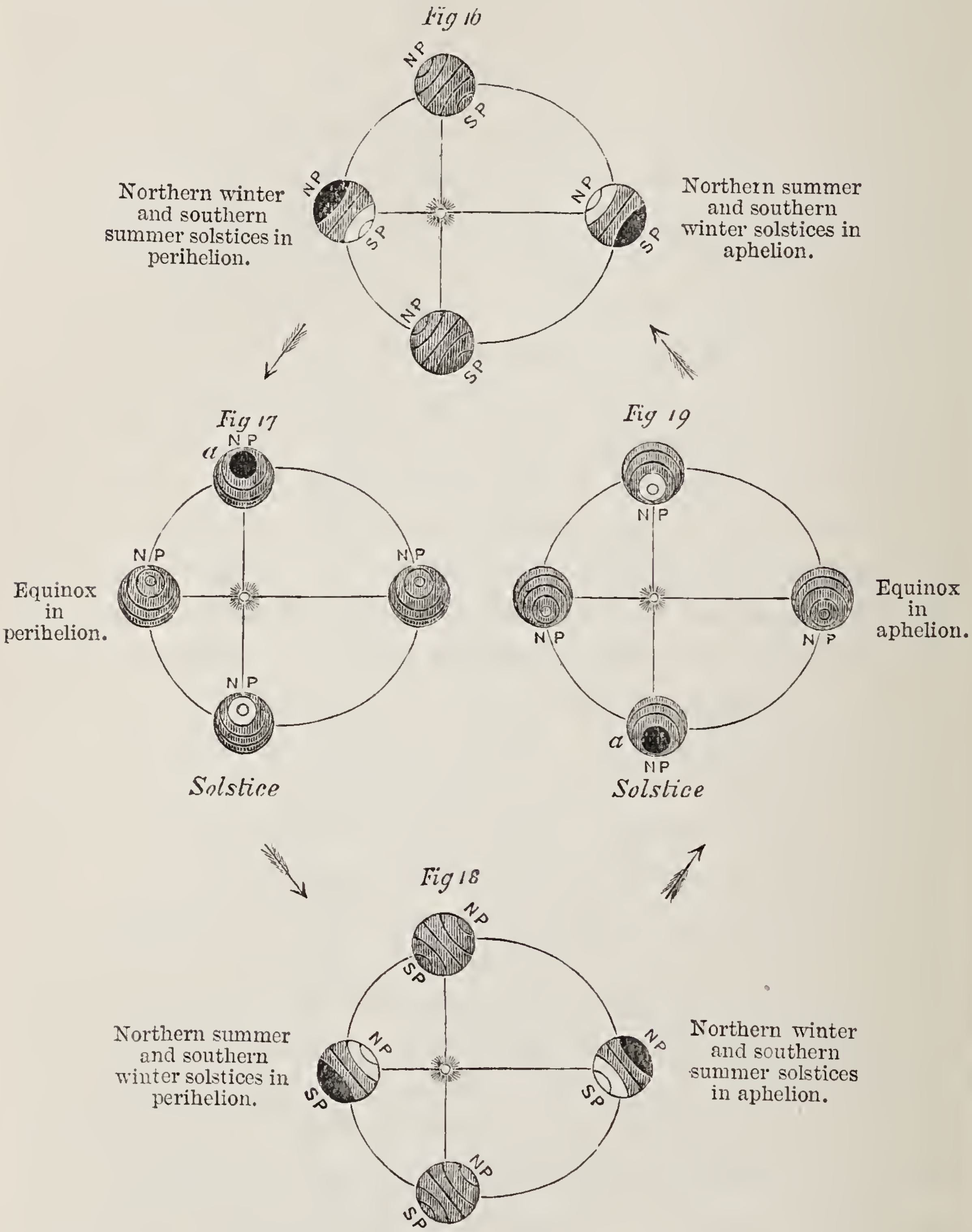


Diagram illustrative of the Precession of the Equinoxes.

In order to give a clear idea of the ellipse, it has been drawn as though the reader looked down upon it directly from above, while the figures of the globe are drawn as they would appear if placed rather more on a level with the eye.

The black patches represent winter; the white patches, summer.

in fig. 18, because the distance of the earth from the sun in the first case is less.

M. Adhémar, in a work entitled 'Les Révolutions de la

Mer,' published in 1840, suggested that a sensible effect has already resulted from the deviation which has occurred since the year 1248, of the position of the perihelion from the time of the winter solstice in the north. By this movement the nearest approach to the sun now occurs eleven days after the shortest day. M. Venetz had previously pointed out, as an historical fact, that before the tenth century the Swiss glaciers were larger than they are now, and that then, after retreating for four centuries, they advanced again, and have been slowly reacquiring their former dimensions. In other words, at that period when the sun was nearest the earth in midwinter or for two centuries before and two after 1248, there was the greatest melting of ice in the northern hemisphere. It may be questioned whether this slight astronomical change, which could hardly produce more than a difference of half a degree Fahrenheit between the cold of the present winter and that of 1248, would be appreciable in the course of 600 years; but the observation may help the reader to understand in what direction the precession of the equinoxes, if capable of producing a sensible change, would now be affecting climate.

It is obvious that this effect would be intensified whenever the ellipticity of the orbit is increased, for the difference of distance between aphelion and perihelion is now only 3,000,000 miles, but it would be at some periods as much as 14,000,000, causing, as Mr. Croll has pointed out, a difference of heat received at the two points amounting to about one-fifth of the entire heat received from the sun, because the amount of such heat varies inversely as the squares of the distance.*

Suggestions by Mr. Croll as to the effects of excentricity on climate.—Upon this difference of heat Mr. Croll has founded a theory which attempts to account for former changes of climate by the tendency which a maximum excentricity would have to exaggerate the cold in that hemisphere in which winter occurred in aphelion.† In consequence, he

* See Herschel's Astronomy, art. 368 *a*.

† Croll on the physical cause of change of climates during geological epochs. Phil. Mag., August 1864.

says, of the lowering of the temperature by one-fifth in that hemisphere in which winter occurs when the earth is farthest from the sun, all the moisture precipitated from the air in high latitudes would fall in the form of snow instead of rain; and the heat in the same hemisphere of summer in perihelion, although one-fifth greater than what we now experience, would be insufficient to remove the accumulation of winter snow. The direct power of the sun's rays would be greatly intensified when the sky was cloudless, but the melting of so much ice would, he thinks, in a great measure neutralise their force by giving rise to fogs and an overcast sky. This point I shall discuss more fully in the sequel (pp. 280 and 289), but it appears to me that he is here obliged to make an assumption for which we have no certain data—namely, that the intensely blazing sun in a clear sky which would first melt the ice would afterwards be sufficiently overcome by fog to check and almost prevent further melting, in spite of the continued supply of excessive heat during the summer. In accordance with this view he maintains that, while one hemisphere during this maximum excentricity would be enduring the extreme cold of a lengthened winter, and having its summer heat chilled by the melting of ice, the other hemisphere would be enjoying simultaneously the perpetual spring alluded to by Herschel; the polar winter occurring in perihelion, when the temperature was one-fifth greater than at present, and there being no accumulation of snow beyond what the sun's rays could dissipate during the course of the year.

He has also endeavoured to show that the vast accumulation of ice which would alternately take place at each pole during that phase of precession in which winter would occur when the planet was farthest from the sun, would so derange the earth's centre of gravity as to draw the ocean towards that pole, and cause the submergence of part of the land. M. Adhémar, in 1843, had already endeavoured to account for certain geological phenomena by a coincidence of the winter solstice with aphelion, but without connecting them, as Mr. Croll has done, with that greater excentricity of the earth's orbit, which must occasionally in the course of ages vastly exaggerate the effects alluded to. Although the deficiency

of our data is such that we cannot yet decide to what extent this excess of ice would act as a disturbing cause, yet, as there can be no doubt that it must have given rise at certain periods to some difference in the ocean's level, we are greatly indebted to those scientific writers who have called attention to a *vera causa* hitherto neglected.

In the memoir above alluded to, little or no influence is ascribed by Mr. Croll to abnormal geographical conditions, such as now prevail; and which, according to the principles explained in the last chapter, I consider by far the most influential in the production of great cold. Granting that under favourable geographical circumstances the greatest accumulation of snow would always take place at that pole where midwinter happened to occur in aphelion, I also think it probable that, be the amount of excentricity great or small, there would be no increase of cold from year to year, so often as the distribution of land and sea is not exceptional, or whenever a normal condition of things obtains as expressed in the ideal map, fig. 13, p. 267. Moreover, it appears to me almost certain, that whenever a deep ocean prevailed at both poles, the astronomical causes alone would be powerless for the storing up of ice, and during extreme excentricity, the minor axis of the ellipse being shortened, the total quantity of heat received from the sun would be slightly in excess of the present,* and so far as it went would be in an opposite direction to that which would bring about glacial periods. In extreme excentricity there is at least as great an excess of heat in summer in perihelion as there is loss in winter in aphelion, so that we cannot suppose the total amount of snow lying on the ground to be increased unless there should intervene some cause to mitigate the extreme heat of summer. This has been supposed by Mr. Croll to be the case when he says, as above, that the first action of the summer sun would be to raise a fog which would effectually prevent the sun's rays from reaching the earth. But in the papers in which he advances this supposition he does not state the reasons why anything like a

* See p. 273; and Meech, Intensity of the Sun's Heat and Light, Smithsonian Contributions, 1857.

universal arctic fog should be produced. The heating effect of the sun, for the first part of the summer at least, is continually increasing, and consequently the power of the heated air to absorb aqueous vapour is also augmenting; it is therefore not easy to see how fogs could arise, except where an abnormal quantity of high snow-covered land was collected around the pole.

Climates of the successive phases of precession with increased excentricity.—But there is another circumstance tending to the equalisation of the heat, which must be borne in mind, lest we should exaggerate the effects of excentricity on climate, even when intensified by such abnormal conditions of the earth's geography as now prevail. We ought not to divide the 21,000 years before spoken of as constituting the cycle caused by precession and the revolution of the apsides into two equal parts, as M. Adhémar and others have proposed, one of which in a given hemisphere should be a cold period when the winters coincide with aphelion, and the other a warm period when the winters coincide with perihelion. For it must be borne in mind that there will be no sharply defined line between the warmest and coldest periods, but a gradual transition between these extremes. We shall get a clearer notion therefore of the varying climatal conditions if we divide the cycle of precession into four quarters (as in figs. 16 to 19, p. 276), in the first of which there is an accumulation of ice in the southern hemisphere, because of the coincidence of the long antarctic night and short days with the greatest distance of the planet from the sun, or, in other words, because the southern winter happens when the earth is at or near aphelion, and granting, for the sake of argument, Mr. Croll's hypothesis of the accumulation of fogs and clouds, the more intense heat of 5,250 summers in perihelion is supposed to be unequal to the task of melting the snows of an equal number of winters. Then follows the next quarter, when the vernal equinox occurs at the least distance from the sun, and an equable climate is produced, whatever be the amount of excentricity; for the 5,250 winters and summers will be of nearly equal duration, and the summer and winter distances from the sun also equal,

both of which causes will combine to make these seasons vary but little from the mean, and will cause a reduction of the snow and ice accumulated in the preceding quarter. In the third quarter the cold of all the winters is neutralised by proximity to the sun, while the heat of the summers is in like manner moderated by the earth's distance from it, so that here again an equal climate is produced. In the fourth quarter, the autumnal equinox falling at or near aphelion, the same effects will be produced as in the second quarter, and there will be no great exaggeration of heat or cold, like that which must take place in the first quarter. This first quarter therefore is the only one in which, under favourable geographical conditions like the present, an accumulation of ice and snow will take place at whichever pole has its winter in aphelion.

Present effect of geographical causes on the climate of the earth.—A good illustration is afforded of the preponderating influence of geographical causes by the result of Dove's observations on the present mean temperature of the whole surface of the globe in perihelion as contrasted with its temperature in aphelion.

The present excentricity of the earth's orbit amounts, as before stated (p. 273), to no more than a million and a half of miles in opposite directions from its mean distance from the sun, which is ninety-one millions. The difference of distance of the earth from the sun, in aphelion and perihelion, is therefore no less than one-thirtieth of the mean distance, and the planet therefore ought to be colder at the one time and hotter at the other, not merely by one-thirtieth of the heat received from the sun, but by about one-fifteenth, because the heat varies inversely as the squares of the distance. Yet, as if in violation of this law, when the temperatures of all places north and south of the line are reduced to an average, it is found that the surface of the whole planet is actually warmer in June than in December, i.e. in aphelion than in perihelion. This result, which in an astronomical point of view appears so paradoxical, is explained in a satisfactory manner when we take into consideration that the effect of land under sunshine is to throw heat into the general atmosphere, and

so distribute it by the carrying power of the air over the whole earth.* For the great extent of land which exists between the equator and the fiftieth degree of north latitude is exposed to the sun's rays during a long summer, whereas the extent of ocean in corresponding latitudes in the southern hemisphere prevents any similar generation of heat during summer, notwithstanding that here, according to Herschel's estimate, the power of the sun is greater by 23° F. when the planet is in perihelion.

Another illustration of the counteracting effect of geographical causes is afforded by the extreme climates of Canada and other parts of North America, as well as of certain parts of Siberia and China, as contrasted with the more equable climates of the southern hemisphere. A very different result might be looked for if the ascendency of astronomical causes were complete; for in that hemisphere where winter coincides with the greatest and summer with the least distance from the sun, the seasons would have been most contrasted were it not that the preponderance of sea as compared to land produces an equable or what is called an 'insular' climate.

The fact that the cold is now greater throughout a large part of the southern hemisphere would seem at first sight almost to demonstrate the truth of the theory that the coincidence of the winter solstice with aphelion exerts a powerful refrigerating effect. But the difference of about 10° F. in temperate latitudes in the southern hemisphere is shown by Dove's tables to be due to a deficiency of land, which is in excess in corresponding latitudes of the northern hemisphere. Without denying that the astronomical cause alluded to may exercise some influence, it is obviously insignificant as contrasted with the power of geographical conditions. Sir John Herschel, indeed, computes on theoretical grounds that there ought to be a difference of 23° F. when two places are compared at the same season and in the same latitudes on opposite sides of the equator; that is to say, the summer coinciding with perihelion ought to have a temperature of $11\frac{1}{2}$° higher, and the winter in aphelion a temperature lower

* Herschel's Astronomy, 1864, p. 236, art. 376.

by the same amount, than the same seasons in the opposite hemisphere, where these astronomical conditions are reversed. The results of observation are not in harmony with this theory, the difference really indicated by the thermometer being only half that which is required by theory. Yet there are some limited areas where, according to Herschel, the excentricity makes itself felt. The heat, he says, in the interior of Australia is greater than in the deserts of North Africa in corresponding latitudes; and he has himself observed the temperature of the surface soil in South Africa to reach 159° F., which is higher than it rises in our hemisphere, where summer does not coincide with perihelion.* The question, however, of the measurement of heat depends upon an arbitrary assumption as to the temperature of space, or the degrees of heat which our thermometers would indicate if they could be placed at some point beyond our atmosphere and shaded from the sun. As it is impossible to test this experimentally, and different physicists of the highest eminence are not agreed even as to the conditions of the problem, I shall not enter into calculations, the accuracy of which cannot at present be depended upon.

The simple fact that totally different climates exist now in the same hemisphere and under the same latitude would alone suffice to prove that their occurrence cannot be exclusively due to astronomical influence. The reader has only to refer to p. 243 to see that the climates of South Georgia and Tierra del Fuego are at present so different that the former might be supposed to belong to a glacial period, while the latter, by its flowers and humming-birds in the winter, and the genera of marine mollusca in the adjoining sea, might indicate to the traveller, as well as to some future geologist, such a temperature as has been spoken of as perpetual spring. This contrast is due to geographical causes, which if reversed, so that Tierra del Fuego became the oceanic island, would reverse the climates also. Mr. Darwin, in the last edition of his 'Origin of Species,'† has inclined towards adopting Mr. Croll's theory of alternate glaciation and perpetual spring in the opposite hemispheres, on the ground that

* Herschel's Astronomy, 1864, art. 369, *note*. † Pp. 450-461.

it would account for some anomalies in the distribution of animals and plants, by affording a refuge for tropical life during a period of extreme cold. But it appears to me that such cases as the one just mentioned of South Georgia and Tierra del Fuego are a warning against assuming that glaciation must be universal in all corresponding latitudes of the same hemisphere, and that until we know what climate the countries now inhabited by tropical animals and plants were enjoying in glacial times, it is premature to contend with imaginary difficulties as to the survival of forms which would have been extinguished if the snow and ice had been universal down to latitude 55°, even over one hemisphere at a time.

How far we may speculate on a probable date for the Glacial Period.—From what I have now said in this and the preceding chapter, it will be seen that I consider the former changes of climate and the quantity of ice now stored up in polar latitudes to have been governed chiefly by geographical conditions. Nevertheless, since I also consider it probable that a much larger excentricity of the earth's orbit if combined with the present excess of polar land would produce an exaggeration of cold in both hemispheres, it becomes a matter of no small interest to ascertain the dates of those variations in the excentricity of the orbit which may throw light on the times when the cold first came on, when it reached its height, and when it was succeeded by the great thaw which reduced the ice to its present limits.

On my applying to the Astronomer Royal, Sir George Airy, for assistance in this enquiry, he suggested to Mr. Stone, of the Greenwich Observatory, to make some of the required calculations; and that eminent mathematician undertook, by the use of Leverrier's formula, to determine when the last high excentricity occurred. He found that it happened 210,065 years ago,* and that no other excentricity approaching to this in amount could be obtained by going back half a million of years from the present era. The difference between the greatest and least distances, at the time alluded to by Mr. Stone, was about eleven millions of miles, while at the maximum the difference would be about fourteen millions.

* Letter to the Author, May 15, 1865; and see Phil. Mag., June 1865.

At present it is about three millions, so that the proportions of distance are expressed by the figures 3 11 14. Hence, as Mr. Stone observes, 'whatever climatic changes may have

Table showing the variations in the excentricity of the earth's orbit for a million years before A.D. 1800, and some of the climatal effects of such variations.

	1	2	3	4
	Number of years before A.D. 1800	Excentricity of orbit	Difference of distance in millions of miles	Number of winter days in excess
	0,	·0168	3	8·1
	50,000	·0131	$2\frac{1}{4}$	6·3
A	100.000	·0473	$8\frac{1}{2}$	23
	150,000	·0332	6	16·1
B a	200,000	·0567	$10\frac{1}{4}$	27·7
B b	210,000	·0575	$10\frac{1}{2}$	27·8
	250.000	.0258	$4\frac{1}{2}$	12·5
	300,000	·0424	$7\frac{3}{4}$	20·6
	350.000	·0195	$3\frac{1}{2}$	9·5
	400.000	·0170	3	8·2
	450,000	·0308	$5\frac{1}{2}$	15
	500,000	·0388	7	18·8
	550,000	·0166	3	8
	600,000	·0417	$7\frac{1}{2}$	20·3
	650,000	·0226	4	11
	700,000	·0220	4	10·2
C a	750,000	·0575	$10\frac{1}{2}$	27·8
C b	800,000	·0132	$2\frac{1}{4}$	6·4
C c	850,000	·0747	$13\frac{1}{2}$	36·4
	900,000	·0102	$1\frac{1}{4}$	4·9
D	950,000	·0517	$9\frac{1}{4}$	25·1
	1,000,000	·0151	$2\frac{3}{4}$	7·3

EXPLANATION OF THE TABLE.

Column 1. Division of a million years preceding 1800 into twenty equal parts.

Column 2, computed by Mr. James Croll by aid of Leverrier's formula, gives the excentricity of the earth's orbit in parts of a unit equal to the mean distance or half the longer diameter of the ellipse.

Column 3, which together with the following column has been computed by Mr. John Carrick Moore, gives in millions of miles the difference between the greatest and least distances of the earth from the sun, during the excentricities given in Column 2.

Column 4 gives the number of days by which winter occurring in aphelion is longer than the summer in perihelion.

taken place at some distant period through the existence of the absolute maximum of excentricity, corresponding and but slightly inferior changes must have taken place about 210,000 years before the beginning of the present century.'

Mr. Croll, following up the series of calculations begun by

Mr. Stone rendered a greater service to science by accomplishing the laborious task of computing the changes of excentricity for a million years preceding and a million following A.D. 1800. I have taken the first two columns of the annexed table from his memoir, and the results given in the other two columns have been computed by my friend Mr. John Carrick Moore, who by his mathematical and geological knowledge has rendered me invaluable assistance in all these enquiries on changes of climate. It appears to me that the third and fourth columns will help the reader more clearly to appreciate the variations in temperature which are indicated by the figures in the second column. A glance at this table will show that there are four periods in the course of the last million of years, namely, those marked A, B, C, D, in which there has been a large excentricity. For in A it was nearly three times as great as it is at present; in B three and a half times; in C we find two periods, one three and a half and the other four and a half times as great, with an intervening small excentricity; and lastly, in the period D, more than three times the present excentricity.

The attempt to assign a chronological value to any of our geological periods except the latest must, in the present state of science, be hopeless. Nevertheless, independently of all astronomical considerations, it must, I think, be conceded, that the period required for the coming on of the greatest cold, and for its duration when most intense, and the oscillations to which it was subject (p. 192), as well as the retreat of the glaciers and the 'great thaw' or disappearance of snow from many mountain-chains where the snow was once perpetual, required not tens but hundreds of thousands of years. Less time would not suffice for the changes in physical geography and organic life of which we have evidence. To a geologist, therefore, it would not appear startling that the greatest cold should be supposed to have coincided with the period B, 200,000 years ago, although this date must be considered as very conjectural, and one which may be as likely to err in deficiency of time as in excess. I formerly speculated* on the more remote periods C and D for

* Principles, 10th ed., 1867.

the Glacial period, but upon reconsideration it appears to me that geographical conditions are so paramount that we must not go further back in time than we are able fairly to assume that the principal geographical features of the continents and oceanic basins approximated to those now prevailing. If, for example, the Alps and Jura were as high or perhaps higher than now, we may suppose that whenever the winter of the northern hemisphere coincided with aphelion during a period of high excentricity, the Alpine glaciers would have been far in excess of what they are now, whereas if we go back 800,000 or 1,000,000 years to C or D, in order to reach a somewhat higher excentricity, we know not how far the geography may have coincided with that now established, so as to allow of the excentricity augmenting or diminishing the glaciation of the poles. There may, for example, have been no Gulf-stream, the Sahara may have been submerged, and a great many other areas may have been so differently circumstanced that it would be rash to reason upon the state of climate, whether general or local.

We have no right to assume that the distance of our planet from the sun during part of the year would cause so much cold as to counterbalance the heat resulting from greater proximity at another period of the year, unless the distribution of land and sea was unfavourable to that interchange of warmth and cold between polar and equatorial regions on which the very existence of ice and snow on the earth depends. If I am right in believing that the present geographical circumstances are exceptional, then the climates of the pole will be equally exceptional, and will have been so during the whole period when the continents and oceans gradually assumed their present form. This form is favourable, as we now see, to the simultaneous glaciation of both polar regions, and we cannot doubt that the local excess of ice and snow will vary in each hemisphere in proportion as winter coincides with aphelion. It is therefore natural that we should find periods in the Newer Pliocene and Post-Tertiary deserving the appellation of 'Glacial,' while a wider geological survey might show us few or no monuments of such glaciation, even in the shape of erratics, although if glacial conditions

had prevailed, they ought to have abounded between the thirtieth and fiftieth parallels of latitude in formations requiring such vast periods for their accumulation as the Cretaceous, Neocomian, and Carboniferous.

With regard to the more recent excentricities of the periods A and B, when a predominance of land in high latitudes may more safely be assumed, the fact which would seem to me most favourable to the connection of a large excentricity with an excess of cold is the following:

By referring to the map of Isothermal Lines (fig. 9, p. 240), the reader will see that the mean annual isothermals of 14°, 23°, 32°, 41°, and 50° Fahr., are all of them in their range from Europe to North America deflected from 13° to 18° of latitude in a southerly direction in their passage from east to west. The late Edward Forbes has also shown in one of his maps,* that the living arctic fauna extends in like manner 10° farther south on the west side of the Atlantic than on the east side. This difference, as before pointed out (p. 239), is dependent on purely geographical and not on astronomical causes; the direction of the Gulf-stream from south-west to north-east—the cold polar current flowing south along the east coast of North America—the extension of the land of the latter continent continuously towards the pole in the same latitudes as those where there is open sea to the north of Europe, are sufficient to explain the present course of the isothermals; and if the cold were now augmented by the coming on of a large excentricity, the isothermals alluded to would exhibit the same curves, their position being shifted farther south because the new refrigerating influence would operate equally on the eastern and western hemisphere. If the effect would not be exactly equal on both sides the Atlantic, it would be in favour of greater curves in the direction in which they now bend, because the increase of snow and ice would be greatest on the side where there is most land in very high latitudes.

Now we find that in the Glacial period all signs of glaciation, such as erratic blocks, scored surfaces of rock, striated boulders, and deposits filled with arctic species of marine

* Memoirs of the Survey of Great Britain, vol. i. plate vii.

shells, are to be seen in full force on the North American continent ten or more degrees farther south than in Europe. If we could assume, therefore, that geographical conditions had been constant, these phenomena would be in favour of our attributing the greater intensity of cold in the Glacial Period to a maximum excentricity. Our full reliance, however, on this line of reasoning is somewhat weakened when we reflect that a moderate amount of geographical change in a very high latitude—such as the addition of some islands near the pole, or the increased height of some of the land now existing between latitudes 70° and 80° N.—might exaggerate the cold both of the eastern and western hemispheres, acting alike on northern Europe and North America. We know, as a positive fact, that geographical changes have taken place in the height and position of land since the commencement of the Glacial Period, although we cannot affirm that when the cold was at its height there was a greater proportion of land in high latitudes than at present. If at that time it were in excess, we are more certain that the change alluded to would intensify the cold than we are that a change of excentricity would have the same effect; for the last-mentioned conclusion depends upon the soundness of the hypothesis that, in spite of the annual supply of solar heat being always equal, the more intense heat of summer cannot overcome the increased winter's cold whenever the latter gives rise to a much greater snowfall.

Evaporation of ice and snow.—Now observations on the Swiss glaciers have shown to what an extent those rivers of ice are often lowered by evaporation, or by the passage of the ice into a gaseous form, without its having passed through the intermediate fluid condition. When certain dry winds blow, the snow wastes away like camphor without melting; and as we see the average number of inches of rainfall to diminish constantly, though very irregularly, as we pass from the equator to the pole, so we may reckon on a diminution of the quantity of snow and the prevalence near the pole of a dry air, especially if there be snow-covered lands farther south intercepting aërial currents blowing

from warmer regions, and causing them to part with their moisture in the form of snow.

Mr. Darwin, during his visit to Central Chili, was informed that during one dry and very long summer all the snow disappeared from Aconcagua, although it attains the height of 23,000 feet. It is probable, he adds, that much of the snow at these great heights is evaporated rather than thawed.*

In the Himalayas, where some of the mountain-peaks attain the height of 29,000 feet, the snow-line on the southern side of the chain occurs at 13,000, and on the northern at 16,000 feet, or, according to some authorities, even at 18,000. 'For the moist winds of the south-west monsoon,' says Herschel, 'deposit their snow almost wholly on the southern side, while the northern is exposed to the evaporation of one of the driest regions of the globe.' In like manner, when winds from the temperate zone first meet the frozen air of the antarctic regions, they will part with their moisture, so that the snow will increase on the outer margin of the antarctic continent rather than in the interior. As it is well known that great falls of snow take place chiefly when the thermometer is about 32° F., and that little, if any, ever falls when the temperature is much lower, it would certainly be rash to assume that intense cold near the pole during the aphelion, when the excentricity is very large, tends to generate more snow than the dry atmosphere can absorb.

Much snow was seen by Rink to have vanished from the surface of Greenland in the latter months of autumn, so that lines of erratic blocks were disclosed to view. In like manner, Ross and Hooker observed blocks of stone on the snows of Victoria Land—facts which would be inexplicable if much of the snow which falls annually were not removed from the surface by evaporation and liquefaction in high latitudes. Mr. Alexander Agassiz, when living on the shores of Lake Superior, describes the thermometer as being at 5° below zero for four months in the year, and says that the average annual snowfall of fifteen years was seventy-two feet. Yet the snow never lay more than six feet thick on the ground, and disappeared completely in the summer, the snow being

* Darwin, Journal of the Beagle, 1845, p. 245.

chiefly got rid of by evaporation like camphor. He also mentions that the ground beneath the snow never froze, and upon this point it is well to bear in mind that a covering of snow extending over a large area and enduring for a long time must have the effect of preventing loss by radiation, snow being a very bad conductor of heat.

It is observed in Canada and New England that parts of a meadow which are laid bare in winter by the wind having blown away its snow are often frozen for a depth of two feet or more, so that, when spring returns, this portion of the surface remains brown and barren, while the rest of the field, having retained its heat during winter in consequence of the covering of snow, is green and clothed with a rapidly growing vegetation. Dr. Hooker found in like manner that after the melting of the snow on the Himalaya the warmth of the soil was far above the mean temperature of the region, owing to the same cause. In this way there may be some compensation, the excess of heat absorbed by the land during a short but hot summer being less freely parted with in winter owing to the snow. This loss by radiation during a protracted winter is only one of many elements as yet undetermined which complicate the problem on which we are speculating.

Absence of recurrent Glacial epochs in the earlier formations.— If we now turn from the physical difficulties raised by the astronomical theory to the question of palæontological evidence, we find that if the sketch which we have given in the tenth and eleventh chapters of the former states of climate revealed to us by palæontological research be an approximation to the truth, glacial periods have not been perpetually recurring in the northern temperate zone, as they ought to have done were a large excentricity alone sufficient, apart from the co-operation of all other causes, to intensify the cold of high latitudes. It was shown that the flora and fauna do not exhibit signs of violent revolutions from hot to cold and from cold to hot periods. On the contrary, the continuity of forms, particularly in the class of reptiles, from the Carboniferous to the Cretaceous period, is opposed to the intercalation of glacial epochs corresponding in importance

to that of Post-Pliocene date. The Carboniferous Period must have endured for a lapse of centuries sufficient to allow several great cycles of excentricity to be gone through. Yet there must have been nevertheless a long suspension in the temperate latitudes of the northern hemisphere of cold such as we now experience, for we do not find in strata of that age 15,000 feet thick in Nova Scotia any proofs of intercalated glacial epochs. The peculiar vegetation of the coal was persistent throughout the greater part of the ages required for the deposition of so great a thickness of sediment, in which one forest after another was buried on the spot where it had grown.*

This absence of recurrent periods of cold is perfectly explicable, if I am right in concluding that they can only be brought about by an abnormal quantity of land in high latitudes; for under ordinary geographical conditions a maximum excentricity would only tend to render the climate less equable, and not colder. If the ocean prevailed in the polar regions there would be no permanent snow, or no more than the summer's thaw would dissipate; and the difference in the total quantity of heat being as 1003 to 1000, may, as Sir J. Herschel observed, be neglected, and would, if appreciable, have a heating and not a refrigerating influence.

We may indeed imagine an extreme excentricity and winter in aphelion to have sometimes co-operated, with favourable geographical conditions, to produce an excess of cold; but we know so little of the probable distribution of land in earlier times that I shall not repeat my former attempt to calculate the possible comparative duration of the Glacial and antecedent Tertiary, Secondary, and Primary Epochs by a comparison of the supposed relative amount of change in the organic world which has been brought about in corresponding periods.

Variation in the obliquity of the ecliptic.—Hitherto we have been considering the effect on climate of changes in the excentricity of the orbit, as if the earth's axis of rotation were always inclined, as now, at an angle of 23° 28′ to the plane

* See Elements of Geology by the Author, p. 482.

of the ecliptic; but it is well known that this angle is made to vary by about forty-eight seconds per century by the action of the planets on the earth, by which the plane of the ecliptic is now becoming more nearly coincident from year to year with the equator. This diminution of the obliquity will go on for ages, after which 'it will again increase, and thus oscillate backwards and forwards about a mean position, the extent of its deviation to one side and the other being less than 1° 21′.'* But Sir John Herschel informed me that although this limit as calculated by Laplace is true as regards the last 100,000 years, yet, if millions of years are taken into account, it is conceivable that the deviation may possibly be sometimes greater, and may even be found to extend as much as three or even four degrees on each side of the mean.† The questions entered into by Laplace and Leverrier respecting secular changes of the ecliptic relative to a fixed plane, and possible changes in the position of the earth's equator, must be the subject of laborious computations before astronomers will have decided what may be the extreme range of obliquity, but they are agreed that it must be confined within very narrow limits. The result of this movement, whether we adopt the higher or lower limit above alluded to, would be to lessen or augment, according to its direction, the effects to which the precessional movement gives rise. Whenever the obliquity is greater than now, more of the arctic and antarctic regions would be exposed to a long night in winter, and consequently the cold at that season would be greater, and under the opposite circumstances the reverse would take place. The bearing of this cause on geological phenomena would be twofold. So often as the extreme of possible obliquity happened to combine with the maximum excentricity and with geographical

* Herschel's Astronomy, art. 640.

† Letter to the Author, Oct. 1866. Mr. Belt remarks (Quart. Journ. of Science, Oct. 1874, p. 443) that when Laplace and Leverrier fixed the limit of variation, it was not known that the diameter of the equatorial circumference is two miles longer in one direction than in the other, and that this would be a disturbing element in the problem. As, however, Sir J. Herschel mentions this difference in his Astronomy, 7th ed. 1864, he was aware of it when he gave me the extreme limit which he considered possible.

circumstances of an abnormal character like those now prevailing in high latitudes, a greater intensity of cold would be produced than could exist without such a combination, and so far this would favour a glacial epoch. But when, on the other hand, the obliquity was at its minimum, the cold would be lessened, even though all the other conditions which promote it were in full force. It may also be remarked that if the obliquity of the ecliptic could ever be diminished to the extent of four degrees below its present inclination, such a deviation would be of geological interest, in so far as it would cause the sun's light to be disseminated over a broader zone inside of the arctic and antarctic circles. Indeed, if the date of its occurrence in past times could be ascertained, this greater spread of the solar rays, implying a shortening of the polar night, might help in some slight degree to account for a vegetation such as now characterises lower latitudes, having had in the Miocene and Carboniferous periods a much wider range towards the pole. Were an adequate supply of light thus afforded, the warmth required by such a flora would rarely have been wanting in past times, for, according to principles before laid down, a more genial climate would usually prevail in high latitudes, that is to say whenever the earth's geography was in a normal state.

In Mr. Meech's valuable paper, before cited (p. 279), he treats of the effects of altered obliquity; but he states* that his results as to the intensity of solar radiation apply only to the outside of the earth's atmosphere. If his readers fail to bear this in mind, they will be in danger of greatly overrating the increased heat in polar regions caused by different phases of precession, excentricity, and obliquity of the ecliptic; for a large deduction will probably have to be made for the greater amount of atmosphere through which the calorific rays must pass in very high latitudes.

The investigation of the true calorific effect of the sun's rays for every 5° of altitude, allowing for the increased length of path traversed by the oblique rays, is given by Sir J. Leslie and Mr. Traill.† From this it appears that the total

* Meech, Smithsonian Contributions, 1857, pp. 21 and 43.

† Article 'Climate,' Encycl. Britann.

annual quantity of heat received at the equator, latitude 45°, and the poles will be as the numbers 115, 51, and 14 respectively. Even these figures represent the comparative quantity of heat at the higher latitudes as being more than the truth; for they are computed on the supposition of constant sunshine. As cloud prevails to a greater extent in the high latitudes than at the equator, the disproportion will be increased.

Supposed variations in the temperature of space.—Another astronomical hypothesis respecting the possible cause of secular variations in climate has been proposed by a distinguished mathematician and philosopher, M. Poisson. He begins by assuming, 1st, that the sun and our planetary system are not stationary, but carried onward by a common movement through space. 2ndly, that every point in space receives heat as well as light from innumerable stars surrounding it on all sides, so that if a right line of indefinite length be produced in any direction from such point, it must encounter a star either visible or invisible to us. 3rdly, he then goes on to assume, that the different regions of space, which in the course of millions of years are traversed by our system, must be of very unequal temperature, inasmuch as some of them must receive a greater, others a less quantity of radiant heat from the great stellar enclosure. If the earth, he continues, or any other large body, pass from a hotter to a colder region, it would not readily lose in the second all the heat which it has imbibed in the first region, but retain a temperature increasing downwards from the surface, as is the actual condition of our planet.*

Now the opinion originally suggested by Sir W. Herschel, that our sun and its attendant planets were all moving onward through space, in the direction of the constellation Hercules, is very generally thought by modern astronomers to be confirmed. But the amount of the movement is still uncertain, and great indeed must be its extent before this cause alone can work any material alteration in the terrestrial climates. Mr. Hopkins, when treating of this theory,

* Poisson, Théorie mathémat. de la Chaleur, Comptes rendus de l'Acad. des Sci., Jan. 30, 1837.

remarked that, so far as we are acquainted with the position of stars not very remote from the sun, they seem to be so distant from each other, that there are no points in space among them where the intensity of radiating heat would be comparable to that which the earth derives from the sun, except at points very near to each star. Thus, in order that the earth should derive a degree of heat from stellar radiation comparable to that now derived from the sun, it must be in close proximity to some particular star, leaving the aggregate effect of radiation from the other stars nearly the same as at present. This approximation, however, to a single star could not take place consistently with the preservation of the motion of the earth about the sun, according to its present laws.

Suppose our sun should approach a star within the present distance of Neptune. That planet could no longer remain a member of the solar system, and the motions of the other planets would be disturbed in a degree which no one has ever contemplated as probable since the existence of the solar system. But such a star, supposing it to be no larger than the sun, and to emit the same quantity of heat, would not send to the earth much more than one-thousandth part of the heat which she derives from the sun, and would therefore produce only a very small change in terrestrial temperature.*

Supposed gradual diminution of the earth's primitive heat.—The gradual diminution of the supposed primitive heat of the globe has been resorted to by many geologists as the principal cause of alterations of climate. The matter of our planet is imagined, in accordance with the conjectures of Leibnitz, to have been originally in an intensely heated state, and to have been parting ever since with portions of its heat, and at the same time contracting its dimensions. There are, undoubtedly, good grounds for inferring, from recent observation and experiment, that the temperature of the earth increases as we descend from the surface to that slight depth to which man can penetrate; but there are no positive proofs of a secular decrease of internal heat accompanied

* Quart. Journ. Geol. Soc. 1852, p. 62.

by contraction. On the contrary, Laplace has shown, by reference to astronomical observations made in the time of Hipparchus, that in the last two thousand years at least there has been no sensible contraction of the globe by cooling; for had this been the case, even to an extremely small amount, the day would have been shortened, whereas its length has certainly not diminished during that period by $\frac{1}{300}$th of a second.

I shall allude in the second volume to many objections which may be urged against the theory of the intense heat of the earth's central nucleus, and shall then enquire how far the observed augmentation of temperature, as we descend below the surface, may be referable to other causes unconnected with the supposed pristine fluidity of the entire globe.

CHAPTER XIV.

UNIFORMITY IN THE SERIES OF PAST CHANGES IN THE ANIMATE AND INANIMATE WORLD.

SUPPOSED ALTERNATE PERIODS OF REPOSE AND DISORDER—OBSERVED FACTS IN WHICH THIS DOCTRINE HAS ORIGINATED—THESE MAY BE EXPLAINED BY SUPPOSING A UNIFORM AND UNINTERRUPTED SERIES OF CHANGES—THREE-FOLD CONSIDERATION OF THIS SUBJECT: FIRST, IN REFERENCE TO THE LAWS WHICH GOVERN THE FORMATION OF FOSSILIFEROUS STRATA, AND THE SHIFTING OF THE AREAS OF SEDIMENTARY DEPOSITION; SECONDLY, IN REFERENCE TO THE LIVING CREATION, EXTINCTION OF SPECIES, AND ORIGIN OF NEW ANIMALS AND PLANTS; THIRDLY, IN REFERENCE TO THE CHANGES PRODUCED IN THE EARTH'S CRUST BY THE CONTINUANCE OF SUBTERRANEAN MOVEMENTS IN CERTAIN AREAS, AND THEIR TRANSFERENCE AFTER LONG PERIODS TO NEW AREAS—ON THE COMBINED INFLUENCE OF ALL THESE MODES AND CAUSES OF CHANGE IN PRODUCING BREAKS AND CHASMS IN THE CHAIN OF RECORDS—CONCLUDING REMARKS ON THE IDENTITY OF THE ANCIENT AND PRESENT SYSTEM OF TERRESTRIAL CHANGES.

Origin of the doctrine of alternate periods of repose and disorder.—It has been truly observed, that when we arrange the known fossiliferous formations in chronological order, they constitute a broken and defective series of monuments: we pass without any intermediate gradations from systems of strata which are horizontal, to other systems which are highly inclined—from rocks of peculiar mineral composition to others which have a character wholly distinct—from one assemblage of organic remains to another, in which frequently nearly all the species, and a large part of the genera, are different. These violations of continuity are so common as to constitute in most regions the rule rather than the exception, and they have been considered by many geologists as conclusive in favour of sudden revolutions in the inanimate and animate world. We have already seen that, according to the speculations of some writers, there have been in the past history of the planet alternate periods of

tranquillity and convulsion, the former enduring for ages, and resembling the state of things now experienced by man; the other brief, transient, and paroxysmal, giving rise to new mountains, seas, and valleys, annihilating one set of organic beings, and ushering in the creation of another.

It will be the object of the present chapter to demonstrate that these theoretical views are not borne out by a fair interpretation of geological monuments. It is true that in the solid framework of the globe we have a chronological chain of natural records, many links of which are wanting: but a careful consideration of all the phenomena leads to the opinion that the series was originally defective—that it has been rendered still more so by time—that a great part of what remains is inaccessible to man, and even of that fraction which is accessible nine-tenths or more are to this day unexplored.

The readiest way, perhaps, of persuading the reader that we may dispense with great and sudden revolutions in the geological order of events is by showing him how a regular and uninterrupted series of changes in the animate and inanimate world must give rise to such breaks in the sequence, and such unconformability of stratified rocks, as are usually thought to imply convulsions and catastrophes. It is scarcely necessary to state that the order of events thus assumed to occur, for the sake of illustration, should be in harmony with all the conclusions legitimately drawn by geologists from the structure of the earth, and must be equally in accordance with the changes observed by man to be now going on in the living as well as in the inorganic creation. It may be necessary in the present state of science to supply some part of the assumed course of nature hypothetically; but, if so, this must be done without any violation of probability, and always consistently with the analogy of what is known both of the past and present economy of our system. Although the discussion of so comprehensive a subject must carry the beginner far beyond his depth, it will also, it is hoped, stimulate his curiosity, and prepare him to read some elementary treatises on geology with advantage, and teach him the bearing on that science

of the changes now in progress on the earth. At the same time it may enable him the better to understand the intimate connection between the Second and Third Books of this work, one of which is occupied with the changes of the inorganic, the latter with those of the organic creation.

In pursuance, then, of the plan above proposed, I will consider in this chapter, first, the laws which regulate the denudation of strata and the deposition of sediment; secondly, those which govern the fluctuation in the animate world; and thirdly, the mode in which subterranean movements affect the earth's crust.

Uniformity of change considered, first, in reference to denudation and sedimentary deposition.—First, in regard to the laws governing the deposition of new strata. If we survey the surface of the globe, we immediately perceive that it is divisible into areas of deposition and non-deposition; or, in other words, at any given time there are spaces which are the recipients, others which are not the recipients, of sedimentary matter. No new strata, for example, are thrown down on dry land, which remains the same from year to year; whereas, in many parts of the bottom of seas and lakes, mud, sand, and pebbles are annually spread out by rivers and currents. There are also great masses of limestone growing in some seas, chiefly composed of corals and shells, or, as in the depths of the Atlantic, of chalky mud made up of foraminifera and diatomaceæ.

As to the dry land, so far from being the receptacle of fresh accessions of matter, it is exposed almost everywhere to waste away. Forests may be as dense and lofty as those of Brazil, and may swarm with quadrupeds, birds, and insects, yet at the end of thousands of years one layer of black mould a few inches thick may be the sole representative of those myriads of trees, leaves, flowers, and fruits, those innumerable bones and skeletons of birds, quadrupeds, and reptiles, which tenanted the fertile region. Should this land be at length submerged, the waves of the sea may wash away in a few hours the scanty covering of mould, and it may merely impart a darker shade of colour to the next stratum of marl,

sand, or other matter newly thrown down. So also at the bottom of the ocean where no sediment is accumulating, seaweed, zoophytes, fish, and even shells, may multiply for ages and decompose, leaving no vestige of their form or substance behind. Their decay, in water, although more slow, is as certain and eventually as complete as in the open air. Nor can they be perpetuated for indefinite periods in a fossil state, unless imbedded in some matrix which is impervious to water, or which at least does not allow a free percolation of that fluid, impregnated, as it usually is, with a slight quantity of carbonic or other acid. Such a free percolation may be prevented either by the mineral nature of the matrix itself, or by the superposition of an impermeable stratum; but if unimpeded, the fossil shell or bone will be dissolved and removed, particle after particle, and thus entirely effaced, unless petrifaction or the substitution of some mineral for the organic matter happen to take place.

That there has been land as well as sea at all former geological periods, we know from the fact that fossil trees and terrestrial plants are imbedded in rocks of every age, except those which are so ancient as to be very imperfectly known to us. Occasionally lacustrine and fluviatile shells, or the bones of amphibious or land reptiles, point to the same conclusion. The existence of dry land at all periods of the past implies, as before mentioned, the partial deposition of sediment, or its limitation to certain areas; and the next point to which I shall call the reader's attention is the shifting of these areas from one region to another.

First, then, variations in the site of sedimentary deposition are brought about independently of subterranean movements. There is always a slight change from year to year, or from century to century. The sediment of the Rhone, for example, thrown into the Lake of Geneva, is now conveyed to a spot a mile and a half distant from that where it accumulated in the tenth century, and six miles from the point where the delta began originally to form. We may look forward to the period when this lake will be filled up, and then the distribution of the transported matter will be suddenly altered, for the mud and sand brought down from the Alps will thenceforth, instead

of being deposited near Geneva, be carried nearly 200 miles southwards, where the Rhone enters the Mediterranean.

In the deltas of large rivers, such as those of the Ganges and Indus, the mud is first carried down for many centuries through one arm, and on this being stopped up it is discharged by another, and may then enter the sea at a point 50 or 100 miles distant from its first receptacle. The direction of marine currents is also liable to be changed by various accidents, as by the heaping up of new sandbanks, or the wearing away of cliffs and promontories.

But, secondly, all these causes of fluctuation in the sedimentary areas are entirely subordinate to those great upward or downward movements of land, which will presently be spoken of, as prevailing over large tracts of the globe. By such elevation or subsidence certain spaces are gradually submerged or made gradually to emerge: in the one case sedimentary deposition may be suddenly renewed after having been suspended for one or more geological periods, in the other as suddenly made to cease after having continued for ages.

If deposition be renewed after a long interval, the new strata will usually differ greatly from the sedimentary rocks previously formed in the same place, and especially if the older rocks have suffered derangement, which implies a change in the physical geography of the district since the previous conveyance of sediment to the same spot. It may happen, however, that, even where the two groups, the superior and the inferior, are horizontal and conformable to each other, they may still differ entirely in mineral character, because, since the origin of the older formation, the geography of some distant country has been altered. In that country rocks before concealed may have become exposed by denudation; volcanos may have burst out and covered the surface with scoriæ and lava; or new lakes, intercepting the sediment previously conveyed from the upper country, may have been formed by subsidence; and other fluctuations may have occurred, by which the materials brought down from thence by rivers to the sea have acquired a distinct mineral character.

It is well known that the stream of the Mississippi is charged with sediment of a different colour from that of the Arkansas and Red Rivers, which are tinged with red mud, derived from rocks of porphyry and red gypseous clays in 'the far west.' The waters of the Uruguay, says Darwin, draining a granitic country, are clear and black; those of the Parana, red.* The mud with which the Indus is loaded, says Burnes, is of a clayey hue; that of the Chenab, on the other hand, is reddish; that of the Sutlej is more pale.† The same causes which make these several rivers, sometimes situated at no great distance the one from the other, to differ greatly in the character of their sediment, will make the waters draining the same country at different epochs, especially before and after great revolutions in physical geography, to be entirely dissimilar. It is scarcely necessary to add that marine currents will be affected in an analogous manner in consequence of the formation of new shoals, the emergence of new islands, the subsidence of others, the gradual waste of neighbouring coasts, the growth of new deltas, the increase of coral reefs, volcanic eruptions, and other changes.

Uniformity of change considered, secondly, in reference to the living creation.—Secondly, in regard to the vicissitudes of the living creation, all are agreed that the successive groups of sedimentary strata found in the earth's crust are not only dissimilar in mineral composition for reasons above alluded to, but are likewise distinguishable from each other by their organic remains. The general inference drawn from the study and comparison of the various groups, arranged in chronological order, is this: that at successive periods distinct tribes of animals and plants have inhabited the land and waters, and that the organic types of the newer formations are more analogous to species now existing than those of more ancient rocks. If we then turn to the present state of the animate creation, and enquire whether it has now become fixed and stationary, we discover that, on the contrary, it is in a state of continual flux—that there are many causes

* Darwin's Journal, p. 163, 2nd ed. p. 139.

† Journ. Roy. Geograph. Soc., vol. iii. p. 142.

in action which tend to the extinction of species, and which are conclusive against the doctrine of their unlimited durability.

There are also causes which give rise to new varieties and races in plants and animals, and new forms are continually supplanting others which had endured for ages. But natural history has been successfully cultivated for so short a period, that a few examples only of local, and perhaps but one or two of absolute, extirpation of species can as yet be proved, and these only where the interference of man has been conspicuous. It will nevertheless appear evident, from the facts and arguments detailed in the chapters which treat of the geographical distribution of species in the next volume, that man is not the only exterminating agent; and that, independently of his intervention, the annihilation of species is promoted by the multiplication and gradual diffusion of every animal or plant. It will also appear that every alteration in the physical geography and climate of the globe cannot fail to have the same tendency. If we proceed still farther, and enquire whether new species are substituted from time to time for those which die out, we find that the successive introduction of new forms appears to have been a constant part of the economy of the terrestrial system, and if we have no direct proof of the fact it is because the changes take place so slowly as not to come within the period of exact scientific observation. To enable the reader to appreciate the gradual manner in which a passage may have taken place from an extinct fauna to that now living, I shall say a few words on the fossils of successive Tertiary periods. When we trace the series of formations from the more ancient to the more modern, it is in these Tertiary deposits that we first meet with assemblages of organic remains having a near analogy to the fauna of certain parts of the globe in our own time. In the Eocene, or oldest subdivisions, some few of the testacea belong to existing species, although almost all of them, and apparently all the associated vertebrata, are now extinct. These Eocene strata are succeeded by a great number of more modern deposits, which depart gradually in the

character of their fossils from the Eocene type, and approach more and more to that of the living creation. In the present state of science, it is chiefly by the aid of shells that we are enabled to arrive at these results, for of all classes the testacea are the most generally diffused in a fossil state, and may be called the medals principally employed by nature in recording the chronology of past events. In the Upper Miocene rocks (No. 5 of the table, p. 135) we begin to find a considerable number, although still a minority, of recent species, intermixed with some fossils common to the preceding, or Eocene, epoch. We then arrive at the Pliocene strata, in which species now contemporary with man begin to preponderate, and in the newest of which nine-tenths of the fossils agree with species still inhabiting the neighbouring sea. It is in the Post-Tertiary strata, where all the shells agree with species now living, that we have discovered the first or earliest known remains of man associated with the bones of quadrupeds, some of which are of extinct species.

In thus passing from the older to the newer members of the Tertiary system, we meet with many chasms, but none which separate entirely, by a broad line of demarcation, one state of the organic world from another. There are no signs of an abrupt termination of one fauna and flora, and the starting into life of new and wholly distinct forms. Although we are far from being able to demonstrate geologically an insensible transition from the Eocene to the Miocene, or even from the latter to the recent fauna, yet, the more we enlarge and perfect our general survey, the more nearly do we approximate to such a continuous series, and the more gradually are we conducted from times when many of the genera and nearly all the species were extinct, to those in which scarcely a single species flourished which we do not know to exist at present. Dr. A. Philippi, indeed, after an elaborate comparison of the fossil tertiary shells of Sicily with those now living in the Mediterranean, announced, as the result of his examination, that there are strata in that island which attest a very gradual passage from a period when only thirteen in a hundred of the shells were like the species now

living in the sea, to an era when the recent species had attained a proportion of ninety-five in a hundred. There is, therefore, evidence, he says, in Sicily of this revolution in the animate world having been effected 'without the intervention of any convulsion or abrupt changes, certain species having from time to time died out, and others having been introduced, until at length the existing fauna was elaborated.'

In no part of Europe is the absence of all signs of man or his works, in strata of comparatively modern date, more striking than in Sicily. In the central parts of that island we observe a lofty table-land and hills, sometimes rising to the height of 3,000 feet, capped with a limestone, in which from 70 to 85 per cent. of the fossil testacea are specifically identical with those now inhabiting the Mediterranean. These calcareous and other argillaceous strata of the same age are intersected by deep valleys which appear to have been gradually formed by denudation, but have not varied materially in width or depth since Sicily was first colonised by the Greeks. The limestone, moreover, which is of so late a date in geological chronology, was quarried for building those ancient temples of Girgenti and Syracuse, of which the ruins carry us back to a remote era in human history. If we are lost in conjectures when speculating on the ages required to lift up these formations to the height of several thousand feet above the sea, and to excavate the valleys, how much more remote must be the era when the same rocks were gradually formed beneath the waters!

The intense cold of the Glacial period was spoken of in the tenth chapter. Although we have not yet succeeded in detecting proofs of the origin of man antecedently to that epoch, we have yet found evidence that most of the testacea, and not a few of the quadrupeds, which preceded, were of the same species as those which followed the extreme cold. To whatever local disturbances this cold may have given rise in the distribution of species, it seems to have done little in effecting their annihilation. We may conclude therefore, from a survey of the tertiary and modern strata, which constitute a more complete and unbroken series than rocks of older date, that the extinction and creation of species

have been, and are, the result of a slow and gradual change in the organic world.

Uniformity of change considered, thirdly, in reference to subterranean movements.—Thirdly, to pass on to the last of the three topics before proposed for discussion, the reader will find in the account given in the Second Book, Vol. II., of the earthquakes recorded in history, that certain countries have, from time immemorial, been rudely shaken again and again; while others, comprising by far the largest part of the globe, have remained to all appearance motionless. In the regions of convulsion rocks have been rent asunder, the surface has been forced up into ridges, chasms have opened, or the ground throughout large spaces has been permanently lifted up above, or let down below, its former level. In the regions of tranquillity some areas have remained at rest, but others have been ascertained, by a comparison of measurements made at different periods, to have risen by an insensible motion, as in Sweden, or to have subsided very slowly, as in Greenland. That these same movements, whether ascending or descending, have continued for ages in the same direction has been established by historical or geological evidence. Thus we find on the opposite coasts of Sweden that brackish water deposits, like those now forming in the Baltic, occur on the eastern side, and upraised strata filled with purely marine shells, now proper to the ocean, on the western coast. Both of these have been lifted up to an elevation of several hundred feet above high-water mark. The rise within the historical period has not amounted to many yards, but the greater extent of antecedent upheaval is proved by the occurrence in inland spots, several hundred feet high, of deposits containing fossil shells of species now living either in the ocean or the Baltic.*

It must in general be more difficult to detect proofs of slow and gradual subsidence than of elevation; but the theory which accounts for the form of circular coral reefs and lagoon islands, and which will be explained in the concluding chapter of this work, will satisfy the reader that there are spaces on the globe, several thousand miles in circumference,

* See vol. ii. p. 185.

throughout which the downward movement has predominated for ages, and yet the land has never, in a single instance, gone down suddenly for several hundred feet at once. Yet geology demonstrates that the persistency of subterranean movements in one direction has not been perpetual throughout all past time. There have been great oscillations of level, by which a surface of dry land has been submerged to a depth of several thousand feet, and then at a period long subsequent raised again and made to emerge. Nor have the regions now motionless been always at rest; and some of those which are at present the theatres of reiterated earthquakes have formerly enjoyed a long continuance of tranquillity. But, although disturbances have ceased after having long prevailed, or have recommenced after a suspension for ages, there has been no universal disruption of the earth's crust or desolation of the surface since times the most remote. The non-occurrence of such a general convulsion is proved by the perfect horizontality now retained by some of the most ancient fossiliferous strata throughout wide areas.

That the subterranean forces have visited different parts of the globe at successive periods is inferred chiefly from the unconformability of strata belonging to groups of different ages. Thus, for example, on the borders of Wales and Shropshire, we find the slaty beds of the ancient Silurian system inclined and vertical, while the beds of the overlying carboniferous shale and sandstone are horizontal. All are agreed that in such a case the older set of strata had suffered great disturbance before the deposition of the newer or carboniferous beds, and that these last have never since been violently fractured, nor have ever been bent into folds, whether by sudden or continuous lateral pressure. On the other hand, the more ancient or Silurian group suffered only a local derangement, and neither in Wales nor elsewhere are all the rocks of that age found to be curved or vertical.

In various parts of Europe, for example, and particularly near Lake Wener in the south of Sweden, and in many parts of Russia, the Silurian strata maintain the most perfect horizontality; and a similar observation may be made respecting

limestones and shales of like antiquity in the great lake district of Canada and the United States. These older rocks are still as flat and horizontal as when first formed; yet, since their origin, not only have most of the actual mountain-chains been uplifted, but some of the very rocks of which those mountains are composed have been formed, some of them by igneous and others by aqueous action.

It would be easy to multiply instances of similar unconformability in formations of other ages; but a few more will suffice. The carboniferous rocks before alluded to as horizontal on the borders of Wales are vertical in the Mendip hills in Somersetshire, where the overlying beds of the New Red Sandstone are horizontal. Again, in the Wolds of Yorkshire the last-mentioned sandstone supports on its curved and inclined beds the horizontal Chalk. The Chalk again is vertical on the flanks of the Pyrenees, and the tertiary strata repose unconformably upon it.

As almost every country supplies illustrations of the same phenomena, they who advocate the doctrine of alternate periods of disorder and repose may appeal to the facts above described, as proving that every district has been by turns convulsed by earthquakes and then respited for ages from convulsions. But so it might with equal truth be affirmed that every part of Europe has been visited alternately by winter and summer, although it has always been winter and always summer in some part of the planet, and neither of these seasons has ever reigned simultaneously over the entire globe. They have been always shifting from place to place; but the vicissitudes which recur thus annually in a single spot are never allowed to interfere with the invariable uniformity of seasons throughout the whole planet.

So, in regard to subterranean movements, the theory of the perpetual uniformity of the force which they exert on the earth's crust is quite consistent with the admission of their alternate development and suspension for long and indefinite periods within limited geographical areas.

If, for reasons before stated, we assume a continual extinction of species and appearance of others on the globe, it will then follow that the fossils of strata formed at two distant

periods on the same spot will differ even more certainly than the mineral composition of those strata. For rocks of the same kind have sometimes been reproduced in the same district after a long interval of time; whereas all the evidence derived from fossil remains is in favour of the opinion that species which have once died out have never been reproduced. The submergence, then, of land must be often attended by the commencement of a new class of sedimentary deposits, characterised by a new set of fossil animals and plants, while the reconversion of the bed of the sea into land may arrest at once and for an indefinite time the formation of geological monuments. Should the land again sink, strata will again be formed; but one or many entire revolutions in animal or vegetable life may have been completed in the interval.

As to the want of completeness in the fossiliferous series, which may be said to be almost universal, we have only to reflect on what has been already said of the laws governing sedimentary deposition, and those which give rise to fluctuations in the animate world, to be convinced that a very rare combination of circumstances can alone give rise to such a superposition and preservation of strata as will bear testimony to the gradual passage from one state of organic life to another. To produce such strata nothing less will be requisite than the fortunate coincidence of the following conditions: first, a never-failing supply of sediment in the same region throughout a period of vast duration; secondly, the fitness of the deposit in every part for the permanent preservation of imbedded fossils; and, thirdly, a gradual subsidence to prevent the sea or lake from being filled up and converted into land.

It will appear in the chapter on coral reefs,* that, in certain parts of the Pacific and Indian Oceans, most of these conditions, if not all, are complied with, and the constant growth of coral, keeping pace with the sinking of the bottom of the sea, seems to have gone on so slowly, for such indefinite periods, that the signs of a gradual change in organic

* See last chapter of vol. ii. of this work.

life might probably be detected in that quarter of the globe if we could explore its submarine geology. Instead of the growth of coralline limestone, let us suppose, in some other place, the continuous deposition of fluviatile mud and sand, such as the Ganges and Brahmapootra have poured for thousands of years into the Bay of Bengal. Part of this bay, although of considerable depth, might at length be filled up before an appreciable amount of change was effected in the fish, mollusca, and other inhabitants of the sea and neighbouring land. But if the bottom be lowered by sinking at the same rate that it is raised by fluviatile mud, the bay can never be turned into dry land. In that case one new layer of matter may be superimposed upon another for a thickness of many thousand feet, and the fossils of the inferior beds may differ greatly from those entombed in the uppermost, yet every intermediate gradation may be indicated in the passage from an older to a newer assemblage of species. Granting, however, that such an unbroken sequence of monuments may thus be elaborated in certain parts of the sea, and that the strata happen to be all of them well adapted to preserve the included fossils from decomposition, how many accidents must still concur before these submarine formations will be laid open to our investigation! The whole deposit must first be raised several thousand feet, in order to bring into view the very foundation; and during the process of exposure the superior beds must not be entirely swept away by denudation.

In the first place, the chances are nearly as three to one against the mere emergence of the mass above the waters, because nearly three-fourths of the globe are covered by the ocean. But if it be upheaved and made to constitute part of the dry land, it must also, before it can be available for our instruction, become part of that area already surveyed by geologists. In this small fraction of land already explored, and still very imperfectly known, we are required to find a set of strata deposited under peculiar conditions, and which, having been originally of limited extent, would have been probably much lessened by subsequent denudation.

Yet it is precisely because we do not encounter at every

step the evidence of such gradations from one state of the organic world to another, that so many geologists have embraced the doctrine of great and sudden revolutions in the history of the animate world. Not content with simply availing themselves, for the convenience of classification, of those gaps and chasms which here and there interrupt the continuity of the chronological series, as at present known, they deduce, from the frequency of these breaks in the chain of records, an irregular mode of succession in the events themselves, both in the organic and inorganic world. But, besides that some links of the chain which once existed are now entirely lost and others concealed from view, we have good reason to suspect that it was never complete originally. It may undoubtedly be said that strata have been always forming somewhere, and therefore at every moment of past time Nature has added a page to her archives; but, in reference to this subject, it should be remembered that we can never hope to compile a consecutive history by gathering together monuments which were originally detached and scattered over the globe. For, as the species of organic beings contemporaneously inhabiting remote regions are distinct, the fossils of the first of several periods which may be preserved in any one country, as in America for example, will have no connection with those of a second period found in India, and will therefore no more enable us to trace the signs of a gradual change in the living creation, than a fragment of Chinese history will fill up a blank in the political annals of Europe.

The absence of any deposits of importance containing recent shells in Chili, or anywhere on the western coast of South America, naturally led Mr. Darwin to the conclusion that 'where the bed of the sea is either stationary or rising, circumstances are far less favourable than where the level is sinking to the accumulation of conchiferous strata of sufficient thickness and extension to resist the average vast amount of denudation.' * In like manner the beds of superficial sand, clay, and gravel, with recent shells, on the coasts of Norway

* Darwin's S. America, pp. 136, 139.

and Sweden, where the land has risen in Post-Tertiary times, are so thin and scanty as to incline us to admit a similar proposition. We may in fact assume that in all cases where the bottom of the sea has been undergoing continuous elevation, the total thickness of sedimentary matter accumulating at depths suited to the habitation of most of the species of shells can never be great, nor can the deposits be thickly covered by superincumbent matter, so as to be consolidated by pressure. When they are upheaved, therefore, the waves on the beach will bear down and disperse the loose materials; whereas, if the bed of the sea subsides slowly, a mass of strata, containing abundance of such species as live at moderate depths, may be formed and may increase in thickness to any amount. It may also extend horizontally over a broad area, as the water gradually encroaches on the subsiding land.

Hence it will follow that great violations of continuity in the chronological series of fossiliferous rocks will always exist, and the imperfection of the record, though lessened, will never be removed by future discoveries. For not only will no deposits originate on the dry land, but those formed in the sea near land, which is undergoing constant upheaval, will usually be too slight in thickness to endure for ages.

In proportion as we become acquainted with larger geographical areas, many of the gaps, by which a chronological table, like that given at page 135, is rendered defective, will be removed. We were enabled by aid of the labours of Professor Sedgwick and Sir Roderick Murchison, to intercalate, in 1838, the marine strata of the Devonian period, with their fossil shells, corals, and fish, between the Silurian and Carboniferous rocks. Previously the marine fauna of these last-mentioned formations wanted the connecting links which now render the passage from the one to the other much less abrupt. In like manner the Upper Miocene has no representative in England, but in France, Germany, and Switzerland it constitutes a most instructive link between the living creation and the middle of the great Tertiary period. Still we must expect, for reasons before stated, that

chasms will for ever continue to occur, in some parts of our sedimentary series.

Concluding remarks on the consistency of the theory of gradual change with the existence of great breaks in the series.—To return to the general argument pursued in this chapter, it is assumed, for reasons above explained, that a slow change of species is in simultaneous operation everywhere throughout the habitable surface of sea and land; whereas the fossilisation of plants and animals is confined to those areas where new strata are produced. These areas, as we have seen, are always shifting their position, so that the fossilising process, by means of which the commemoration of the particular state of the organic world, at any given time, is effected, may be said to move about, visiting and revisiting different tracts in succession.

To make still more clear the supposed working of this machinery, I shall compare it to a somewhat analogous case that might be imagined to occur in the history of human affairs. Let the mortality of the population of a large country represent the successive extinction of species, and the births of new individuals the introduction of new species. While these fluctuations are gradually taking place everywhere, suppose commissioners to be appointed to visit each province of the country in succession, taking an exact account of the number, names, and individual peculiarities of all the inhabitants, and leaving in each district a register containing a record of this information. If, after the completion of one census, another is immediately made on the same plan, and then another, there will at last be a series of statistical documents in each province. When those belonging to any one province are arranged in chronological order, the contents of such as stand next to each other will differ according to the length of the intervals of time between the taking of each census. If, for example, there are sixty provinces, and all the registers are made in a single year and renewed annually, the number of births and deaths will be so small, in proportion to the whole of the inhabitants, during the interval between the compiling of two consecutive documents, that the individuals described in such documents will be

nearly identical; whereas, if the survey of each of the sixty provinces occupies all the commissioners for a whole year, so that they are unable to revisit the same place until the expiration of sixty years, there will then be an almost entire discordance between the persons enumerated in two consecutive registers in the same province. There are, undoubtedly, other causes, besides the mere quantity of time, which may augment or diminish the amount of discrepancy. Thus, at some periods a pestilential disease may have lessened the average duration of human life; or a variety of circumstances may have caused the births to be unusually numerous, and the population to multiply; or a province may be suddenly colonised by persons migrating from surrounding districts.

These exceptions may be compared to the accelerated rate of fluctuations in the fauna and flora of a particular region, in which the climate and physical geography may be undergoing an extraordinary degree of alteration.

But I must remind the reader that the case above proposed has no pretensions to be regarded as an exact parallel to the geological phenomena which I desire to illustrate; for the commissioners are supposed to visit the different provinces in rotation; whereas the commemorating processes by which organic remains become fossilised, although they are always shifting from one area to the other, are yet very irregular in their movements. They may abandon and revisit many spaces again and again, before they once approach another district; and, besides this source of irregularity, it may often happen that, while the depositing process is suspended, denudation may take place, which may be compared to the occasional destruction by fire or other causes of some of the statistical documents before mentioned. It is evident that where such accidents occur the want of continuity in the series may become indefinitely great, and that the monuments which follow next in succession will by no means be equidistant from each other in point of time.

If this train of reasoning be admitted, the occasional distinctness of the fossil remains, in formations immediately in contact, would be a necessary consequence of the existing

laws of sedimentary deposition and subterranean movement, accompanied by a constant dying-out and renovation of species.

As all the conclusions above insisted on are directly opposed to opinions still popular, I shall add another comparison, in the hope of preventing any possible misapprehension of the argument. Suppose we had discovered two buried cities at the foot of Vesuvius, immediately superimposed upon each other, with a great mass of tuff and lava intervening, just as Portici and Resina, if now covered with ashes, would overlie Herculaneum. An antiquary might possibly be entitled to infer, from the inscriptions on public edifices, that the inhabitants of the inferior and older city were Greeks, and those of the modern towns Italians. But he would reason very hastily if he also concluded from these data, that there had been a sudden change from the Greek to the Italian language in Campania. But if he afterwards found *three* buried cities, one above the other, the intermediate one being Roman, while, as in the former example, the lowest was Greek and the uppermost Italian, he would then perceive the fallacy of his former opinion, and would begin to suspect that the catastrophes, by which the cities were inhumed, might have no relation whatever to the fluctuations in the language of the inhabitants; and that, as the Roman tongue had evidently intervened between the Greek and Italian, so many other dialects may have been spoken in succession, and the passage from the Greek to the Italian may have been very gradual, some terms growing obsolete, while others were introduced from time to time.

If this antiquary could have shown that the volcanic paroxysms of Vesuvius were so governed as that cities should be buried one above the other, just as often as any variation occurred in the language of the inhabitants, then, indeed, the abrupt passage from a Greek to a Roman, and from a Roman to an Italian city, would afford proof of fluctuations no less sudden in the language of the people.

So, in Geology, if we could assume that it is part of the plan of Nature to preserve, in every region of the globe, an unbroken series of monuments to commemorate the vicissi-

tudes of the organic creation, we might infer the sudden extirpation of species, and the simultaneous introduction of others, as often as two formations in contact are found to include dissimilar organic fossils. But we must shut our eyes to the whole economy of the existing causes, aqueous, igneous, and organic, if we fail to perceive *that such is not the plan of Nature.*

I shall now conclude the discussion of a question with which we have been occupied since the beginning of the fifth chapter—namely, whether there has been any interruption, from the remotest periods, of one uniform and continuous system of change in the animate and inanimate world. We were induced to enter into that enquiry by reflecting how much the progress of opinion in Geology had been influenced by the assumption that the analogy was slight in kind, and still more slight in degree, between the causes which produced the former revolutions of the globe, and those now in every-day operation. It appeared clear that the earlier geologists had not only a scanty acquaintance with existing changes, but were singularly unconscious of the amount of their ignorance. With the presumption naturally inspired by this unconsciousness, they had no hesitation in deciding at once that time could never enable the existing powers of nature to work out changes of great magnitude, still less such important revolutions as those which are brought to light by Geology. They therefore felt themselves at liberty to indulge their imaginations in guessing at what *might be*, rather than enquiring *what is*; in other words, they employed themselves in conjecturing what might have been the course of Nature at a remote period, rather than in the investigation of what was the course of Nature in their own times.

It appeared to them far more philosophical to speculate on the possibilities of the past, than patiently to explore the realities of the present; and, having invented theories under the influence of such maxims, they were consistently unwilling to test their validity by the criterion of their accordance with the ordinary operations of Nature. On the contrary, the claims of each new hypothesis to credibility appeared

enhanced by the great contrast, in kind or intensity, of the causes referred to and those now in operation.

Never was there a dogma more calculated to foster indolence, and to blunt the keen edge of curiosity, than this assumption of the discordance between the ancient and existing causes of change. It produced a state of mind unfavourable in the highest degree to the candid reception of the evidence of those minute but incessant alterations which every part of the earth's surface is undergoing, and by which the condition of its living inhabitants is continually made to vary. The student, instead of being encouraged with the hope of interpreting the enigmas presented to him in the earth's structure—instead of being prompted to undertake laborious enquiries into the natural history of the organic world, and the complicated effects of the igneous and aqueous causes now in operation—was taught to despond from the first. Geology, it was affirmed, could never rise to the rank of an exact science; the greater number of phenomena must for ever remain inexplicable, or only be partially elucidated by ingenious conjectures. Even the mystery which invested the subject was said to constitute one of its principal charms, affording, as it did, full scope to the fancy to indulge in a boundless field of speculation.

The course directly opposed to this method of philosophising consists in an earnest and patient enquiry, how far geological appearances are reconcilable with the effect of changes now in progress, or which may be in progress in regions inaccessible to us, but of which the reality is attested by volcanos and subterranean movements. It also endeavours to estimate the aggregate result of ordinary operations multiplied by time, and cherishes a sanguine hope that the resources to be derived from observation and experiment, or from the study of Nature such as she now is, are very far from being exhausted. For this reason all theories are rejected which involve the assumption of sudden and violent catastrophes and revolutions of the whole earth, and its inhabitants—theories which are restrained by no reference to existing analogies, and in which a desire is manifested to cut, rather than patiently to untie, the Gordian knot.

We have now, at least, the advantage of knowing, from experience, that an opposite method has always put geologists on the road that leads to truth—suggesting views which, although imperfect at first, have been found capable of improvement, until at last adopted by universal consent; while the method of speculating on a former distinct state of things and causes has led invariably to a multitude of contradictory systems, which have been overthrown one after the other—have been found incapable of modification—and which have often required to be precisely reversed.

The remainder of this work will be devoted to an investigation of the changes now going on in the crust of the earth and its inhabitants. The importance which the student will attach to such researches will mainly depend on the degree of confidence which he feels in the principles above expounded. If he firmly believes in the resemblance or identity of the ancient and present system of terrestrial changes, he will regard every fact collected respecting the causes in diurnal action as affording him a key to the interpretation of some mystery in the past. Events which have occurred at the most distant periods in the animate and inanimate world will be acknowledged to throw light on each other, and the deficiency of our information respecting some of the most obscure parts of the present creation will be removed. For as, by studying the external configuration of the existing land and its inhabitants, we may restore in imagination the appearance of the ancient continents which have passed away, so may we obtain from the deposits of ancient seas and lakes an insight into the nature of the subaqueous processes now in operation, and of many forms of organic life which, though now existing, are veiled from sight. Rocks, also, produced by subterranean fire in former ages, at great depths in the bowels of the earth, present us, when upraised by gradual movements, and exposed to the light of heaven, with an image of those changes which the deep-seated volcano may now occasion in the nether regions. Thus, although we are mere sojourners on the surface of the planet, chained to a mere point in space, enduring but for a moment of time, the human mind is not only enabled to number worlds beyond

the unassisted ken of mortal eye, but to trace the events of indefinite ages before the creation of our race, and is not even withheld from penetrating into the dark secrets of the ocean, or the interior of the solid globe; free, like the spirit which the poet described as animating the universe,

> ———ire per omnes
> Terrasque, tractusque maris, cœlumque profundum.

BOOK II.

CHANGES IN THE INORGANIC WORLD NOW IN PROGRESS.

CHAPTER XV.

AQUEOUS CAUSES.

DIVISION OF THE SUBJECT INTO CHANGES OF THE ORGANIC AND INORGANIC WORLD—INORGANIC CAUSES OF CHANGE DIVIDED INTO AQUEOUS AND IGNEOUS—AQUEOUS CAUSES FIRST CONSIDERED—FALL OF RAIN—RECENT RAIN-PRINTS IN MUD—EARTH-PYRAMIDS FORMED BY RAIN IN THE TYROL AND SWISS ALPS—DWARF'S TOWER NEAR VIESCH—DESTROYING AND TRANSPORTING POWER OF RUNNING WATER—NEWLY-FORMED VALLEYS IN GEORGIA—SINUOSITIES OF RIVERS—TWO STREAMS WHEN UNITED DO NOT OCCUPY A BED OF DOUBLE SURFACE—INUNDATIONS IN SCOTLAND—FLOODS CAUSED BY LANDSLIPS IN THE WHITE MOUNTAINS—BURSTING OF A LAKE IN SWITZERLAND—DEVASTATIONS CAUSED BY THE ANIO AT TIVOLI—EXCAVATIONS IN THE LAVAS OF ETNA BY SICILIAN RIVERS—GORGE OF THE SIMETO—GRADUAL RECESSION OF THE CATARACT OF NIAGARA.

Geology was defined to be the science which investigates the former changes that have taken place in the organic as well as in the inorganic kingdoms of Nature. As vicissitudes in the inorganic world are most apparent, and as on them many fluctuations in the animate creation must depend, they may claim our first consideration. The great agents of change in the inorganic world may be divided into two principal classes, the aqueous and the igneous. To the aqueous belong Rain, Rivers, Springs, Currents, and Tides, and the action of Frost and Snow; to the igneous, Volcanos and Earthquakes. Both these classes are instruments of degradation as well as of reproduction; but they may also be regarded as antagonist forces. For the aqueous agents are incessantly labouring to reduce the inequalities of the earth's surface to a level; while the igneous are equally active in restoring

the unevenness of the external crust, partly by heaping up new matter in certain localities, and partly by depressing one portion, and forcing out another, of the earth's envelope.

It is difficult, in a scientific arrangement, to give an accurate view of the combined effects of so many forces in simultaneous operation; because when we consider them separately, we cannot easily estimate either the extent of their efficacy or the kind of results which they produce. We are in danger, therefore, when we attempt to examine the influence exerted singly by each, of overlooking the modifications which they produce on one another; and these are so complicated, that sometimes the igneous and aqueous forces co-operate to produce a joint effect, to which neither of them unaided by the other could give rise,—as when repeated earthquakes unite with running water to widen a valley; or when a thermal spring rises up from a great depth, and conveys the mineral ingredients with which it is impregnated from the interior of the earth to the surface. Sometimes the organic combine with the inorganic causes; as when a reef, composed of shells and corals, protects one line of coast from the destroying power of tides or currents, and turns them against some other point; or when drift timber, floated into a lake, fills a hollow to which the stream would not have had sufficient velocity to convey earthy sediment.

It is necessary, however, to divide our observations on these various causes, and to classify them systematically, endeavouring as much as possible to keep in view that the effects in nature are mixed and not simple, as they may appear in an artificial arrangement.

In treating, in the first place, of the aqueous causes, we may consider them under two divisions: first, those which are connected with the circulation of water from the land to the sea, under which are included the phenomena of rain, rivers, glaciers, and springs; secondly, those which arise from the movements of water in lakes, seas, and the ocean, wherein are comprised the phenomena of waves, tides, and currents. In turning our attention to the former division, we find that the effects of rivers may be subdivided into, first, those of a destroying and transporting, and, secondly, those

of a renovating nature; in the former are included the erosion of rocks and the transportation of matter to lower levels; in the renovating class, the formation of deltas by the influx of sediment, and the shallowing of seas; but these processes are so intimately related to each other, that it will not always be possible to consider them under their separate heads.

ACTION OF RAIN.

Variations in average rainfall.—It is well known that the capacity of the atmosphere to absorb aqueous vapour, and hold it in suspension, increases with every increment of temperature. This capacity is also found to augment in a higher ratio than the augmentation of the heat. Hence, as was first suggested by the geologist Dr. Hutton, when two volumes of air, of different temperatures, both saturated with moisture, mingle together, clouds and rain are produced; for a mean degree of heat having resulted from the union of the two moist airs, the excess of vapour previously held in suspension by the warmer of the two is given out, and if it be in sufficient abundance is precipitated in the form of rain.

As the temperature of the atmosphere diminishes gradually from the equator towards the pole, the evaporation of water and the quantity of rain diminish also. According to Humboldt's computation, the average annual depth of rain at the equator is 96 inches, while in lat. 45° it is only 29 inches, and in lat. 60° not more than 17 inches. But there are so many disturbing causes, that the actual discharge, in any given locality, may deviate very widely from this rule. In England, for example, where the average fall at London is 24½ inches, as ascertained at the Greenwich Observatory, there is such irregularity in some districts, that while at Whitehaven, in Cumberland, there fell in 1849, 32 inches, the quantity of rain in Borrowdale, near Keswick (only 15 miles to the eastward), was no less than 142 inches! * As a rule, the amount of rain in the mountainous parts of Great Britain is more than double that which falls in the less elevated regions. The mean yearly fall of rain at Upsala,

* Miller, Phil. Trans. 1851, p 155.

near the shores of the Baltic, lat. 60° N., is nearly 16 inches, while at Bergen on the Atlantic coast, in the same lat. and only 440 miles distant, the fall, according to Professor J. D. Forbes, is 77 inches. This difference arises from the position of Bergen on the shore of the ocean where the prevailing westerly winds discharge their moisture before crossing Norway and Sweden, on their way to the borders of the Baltic. Winds blowing from the sea are generally surcharged with moisture, while those blowing from the land are comparatively dry, and it is almost everywhere found that the quantity of rain diminishes as we proceed from the borders of the ocean into the interior of continents. In India, Colonel Sykes found by observations made in 1847 and 1848 that at places situated between 17° and 18° north lat., on a line drawn across the Western Ghauts in the Deccan, the average fall of rain, diminishing as we proceed eastward, varied from 219 to 21 inches.* The annual average in Bengal is probably below 80 inches, yet Dr. Joseph Hooker witnessed at Chirapoonjee, in the year 1850, a fall of 30 inches in 24 hours, and in the same place during a residence of six months (from June to November) 530 inches! This occurred on the south face of the Khasia (or Garrow) mountains in Eastern Bengal (see map, p. 463), where the fall during the whole of the same year probably exceeded 600 inches. So extraordinary a discharge of water is very local, as will presently be seen, and may be thus accounted for. Warm, southerly winds, blowing over the Bay of Bengal, and becoming laden with vapour during their passage, reach the low level delta of the Ganges and Brahmapootra, where the ordinary heat exceeds that of the sea, and where evaporation is constantly going on from countless marshes and the arms of the great rivers. A mingling of two masses of damp air of different temperatures probably causes the fall of 70 or 80 inches of rain, which takes place on the plains. The monsoon, having crossed the delta, impinges on the Khasia mountains, which rise abruptly from the plain to a mean elevation of between 4,000 and 5,000 feet. Here the wind not only encounters the cold air of the mountains, but, what is far more effective as a refrigerating

* Phil. Trans. 1850, p. 354.

cause, the aërial current is made to flow upwards, and to ascend to a height of several thousand feet above the sea. Both the air and the vapour contained in it, being thus relieved of much atmospheric pressure, expand suddenly and are cooled by rarefaction. The vapour is condensed, and about 500 inches of rain are thrown down annually, nearly twenty times as much as falls in Great Britain in a year, and almost all of it poured down in six months. The channel of every torrent and river is swollen at this season, and much sandstone and other rocks are reduced to sand and gravel by the flooded streams. So great is the superficial waste (or *denudation*), that what would otherwise be a rich and luxuriantly wooded region is converted into a wild and barren moorland.

After the current of warm air has been thus drained of a large portion of its moisture, it still continues its northerly course to the opposite flank of the Khasia range, only 20 miles farther north, and here the fall of rain is reduced to 70 inches in the year. The same wind then blows northwards across the valley of the Brahmapootra, and at length arrives so dry and exhausted at the Bhootan Himalaya (lat. 28° N.), that those mountains, up to the height of 5,000 feet, are naked and sterile, and all their outer valleys arid and dusty. The aërial current still continuing its northerly course and ascending to a higher region, becomes further cooled, condensation again ensues, and Bhootan, above 5,000 feet, is densely clothed with vegetation.*

In another part of India, immediately to the westward, similar phenomena are repeated. The same warm and humid winds, copiously charged with aqueous vapour from the Bay of Bengal, hold their course due north for 300 miles, across the flat and hot plains of the Ganges, till they encounter the lofty Sikkim mountains. (See map, p. 468.) On the southern flank of these they discharge such a deluge of rain that the rivers in the rainy season rise twelve feet in as many hours. Numerous landslips, some of them extending three or four thousand feet along the face of the mountains, composed of fragments of granite, gneiss, and slate, descend into the beds of streams, and dam them up for a time, causing

* Hooker's Himalayan Journal, ined.

temporary lakes, which soon burst their barriers. 'Day and night,' says Dr. Hooker, 'we heard the crashing of falling trees, and the sound of boulders thrown violently against each other in the beds of torrents. By such wear and tear rocky fragments swept down from the hills are in part converted into sand and fine mud; and the turbid Ganges, during its inundation, derives more of its sediment from this source than from the waste of the fine clay of the alluvial plains below.'*

In the districts above alluded to, and in other regions on the verge of the tropics, a greater quantity of rain falls annually than at the equator.

Rainless regions are generally situated in the interior of great continents, as in the great Sahara of Africa, and in parts of Arabia and Persia. In these cases, the moisture which the winds derive from the nearest sea is expended on the lands nearer the coasts. If there are exceptions to this rule, or coast regions destitute of rain, as that extending from the north of Chili in lat. 30° south to Peru in lat. 8° south, it is where the prevailing winds are intercepted by a chain like the Andes, and made to part with all their moisture before they reach the lower regions to the leeward.

From such facts the reader will infer that in the course of successive geological periods there will be great variations in the quantity of rain falling in one and the same region. At one period there may be no rain during the year; at another, a fall of 100 or 500 inches; and these two last averages may occur on the opposite flanks of a mountain-chain not more than 20 miles wide. While, therefore, the valleys in one district are widened and deepened annually, they may remain stationary in another, the superficial soil being protected from waste by a dense covering of vegetation.

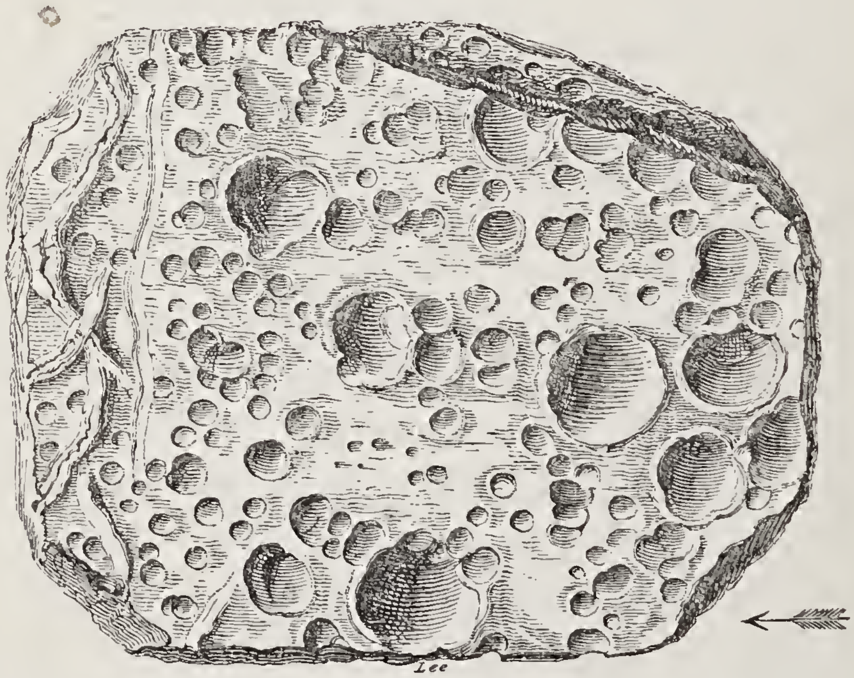
In the course of ages, the height of the land and its position relatively to the ocean will be more or less changed, and we must be careful, when speculating on the quantity of pluvial action in past ages, and the rate of the excavation of valleys, to remember, that there may have been periods of drought as well as of flood, the fall being in defect, as well as in excess, of the present annual mean.

* Hooker's Himalayan Journal, ined.

Recent rain-prints.—When examining, in 1842, the extensive mud-flats of Nova Scotia, which are exposed at low tide on the borders of the Bay of Fundy, I observed not only the foot-prints of birds which had recently passed over the mud, but also very distinct impressions of rain-drops. A peculiar combination of circumstances renders these mud-flats admirably fitted to receive and retain any markings which may happen to be made on their surface. The sediment with which the waters are charged is extremely fine, being derived from the destruction of cliffs of red sandstone and shale, and, as the tides rise fifty feet and upwards, large areas are laid dry for nearly a fortnight between the spring and neap tides. In this interval the mud is baked in summer by a hot sun, so that it solidifies and becomes traversed by cracks, caused by shrinkage. Portions of the hardened mud may then be taken up and removed without injury; and a cross section of it exhibits numerous layers, formed by successive tides, each layer being usually very thin, sometimes only one-tenth of an inch thick. When a shower of rain falls, the highest portion of the mud-covered flat is usually too hard to receive any impressions; while that recently uncovered by the tide near the water's edge is too soft. Between these areas a zone occurs, almost as smooth and even as a looking-glass, on which every drop forms a cavity of circular or oval form, and, if the shower be transient, these pits retain their shape permanently, being dried by the sun, and being then too firm to be effaced by the action of the succeeding tide, which deposits upon them a new layer of mud. Hence we often find, on splitting open a slab an inch or more thick, on the upper surface of which the marks of recent rain occur, that an inferior layer, deposited during some previous rise of the tide, exhibits on its under side perfect casts of rain-prints, which stand out in relief, the moulds of the same being seen on the layer below. But in some cases, especially in the more sandy layers, the markings have been somewhat blunted by the tide, and by several rain-prints having been joined into one by a repetition of drops falling on the same spot; in which case the casts present a very irregular and blistered appearance.

The finest examples which I have seen of these rain-prints were sent to me by Dr. Webster, from Kentville, on the borders of the Bay of Mines, in Nova Scotia. They were made by a heavy shower, which fell on the 21st of July 1849, when the rise and fall of the tides were at their maximum. The impressions (see fig. 20) consist of cup-shaped or hemispherical cavities, the average size of which is from one-eighth to one-tenth of an inch across, but the largest are fully half an inch in diameter, and one-tenth of an inch deep. The depth is chiefly below the general surface or plane of stratification, but the walls of the cavity consist partly of a prominent rim of sandy mud, formed of the matter which has been forcibly expelled from the pit. All the cavities, having an oval form, are deeper at one end, where they have also a higher rim,

Fig. 20.



Recent rain-prints, formed July 21, 1849, at Kentville, Bay of Fundy, Nova Scotia. The arrow represents the direction of the shower.

and all the deep ends have the same direction, showing towards which quarter the wind was blowing. Two or more drops are sometimes seen to have interfered with each other; in which case it is usually possible to determine which drop fell last, its rim being unbroken.

On some of the specimens the winding tubular tracks of worms are seen, which have been bored just beneath the surface (see fig. 20, *left side*). They occasionally pass under the

middle of a rain-mark, having been formed subsequently. Sometimes the worms have dived beneath the surface, and then reappeared. All these appearances, both of rain-prints and worm-tracks, are of great geological interest, as their exact counterparts are seen in rocks of various ages even in formations of very high antiquity (e.g. the Carboniferous).* Small cavities, often corresponding in size to those produced by rain, are also caused by air-bubbles rising up through sand or mud; but these differ in character from rain-prints, being usually deeper than they are wide, and having their sides steeper. These, indeed, are occasionally vertical, or over-arching, the opening at the top being narrower than the pit below. In their mode, also, of mutual interference they are unlike rain-prints.†

In consequence of the effects of mountains in cooling currents of moist air, and causing the condensation of aqueous vapour in the manner above described (p. 323), it follows that in every country, as a general rule, the more elevated regions become perpetual reservoirs of water, which descends and irrigates the lower valleys and plains. The largest quantity of water is first carried to the highest region, and made to descend by steep declivities towards the sea; so that it acquires superior velocity, and removes more soil than it would do if the rain had been distributed over the plains and mountains equally in proportion to their relative areas. The water is also made by these means to pass over the greatest distances before it can regain the sea.

Earth-pyramids or stone-capped pillars of Botzen in the Tyrol.—It is not often that the effects of the denuding action of rain can be studied separately or as distinct from those of running water. There are, however, several cases in the Alps, and especially in the Tyrol near Botzen, which present a marked exception to this rule, where columns of indurated mud, varying in height from twenty to a hundred feet, and usually capped by a single stone, have been separated by rain from the terrace of which they once formed a part, and now

* See Elements of Geology, Index, Rain-prints.'

† See Lyell on recent and fossil rains. Quart. Journ. Geol. Soc. 1851, vol. vii. p. 239.

stand at various levels on the steep slopes bounding narrow valleys. Botzen is situated on the Eisack, two miles above the junction of that river with the Adige, and is 836 feet above the sea. It is in the valleys of two tributary streams which join the Eisack a short distance above Botzen, that the principal groups of pillars occur. Those nearest to the town and situated about a league and a half to the N.E. of it, are in the ravine of the Katzenbach, elevated about 1,700 feet above Botzen; they are the most remarkable of any for their number, size, and beauty. The other pillars occur in the ravine of the Finsterbach, near Klobenstein, at the height of about 2,200 feet above Botzen, and three and a half leagues N.E. of that town. These I shall describe more particularly, as the late Sir John F. W. Herschel had the kindness to enable me to give an accurate representation of them drawn by himself in 1824, by the aid of the camera lucida. I have not room to give his entire drawing, but have selected a part of it, representing the entrance of a tributary ravine into the main valley. (See Plate II.) In such smaller ravines, the same features which are seen on the boundary cliffs of the main valley are repeated, with no other difference than the diminished distance which separates the opposite banks, and the lesser size and number of the columns stretching from the top of each bank down to the brook which flows at the bottom. The breadth of the valley of the Finsterbach is between 600 and 700 feet, and its depth from 400 to 500. The pillars are many hundreds in number, and the precipitous banks from which they spring slope at angles of from 32° to 45°. The lower part of each column has usually several flat sides, so that it assumes a pyramidal instead of a conical shape. The columns consist of red unstratified mud, with pebbles and angular pieces of stone, large and small, irregularly dispersed through them. The whole mass, in short, out of which they are shaped answers in character to the moraine of a glacier, and some of the included fragments of rock have one or more of their faces smoothed or polished, furrowed and scratched, in a manner which clearly indicates their glacial origin. The stones have not their longer axes arranged in one direction, as would be

VIEW OF EARTH-PILLARS OF RITTEN, ON THE FINSTERBACH, NEAR BOTZEN, TYROL.

(From the original Sketch of Sir John F. W. Herschel, taken with the Camera Lucida, September 11, 1821.) See p. 330.

the case if they had been deposited by running water. The matrix of hard mud has been derived evidently from the decomposition of the red porphyry, of which the whole of this country is made up, and the most numerous and largest of the capping-stones consist of the same porphyry; but blocks of granite two or three feet in diameter, which must have come from a great distance, as well as boulders of a hard chlorite rock equally foreign to the immediate neighbourhood, are also scattered sparingly through the reddish matrix. The Finsterbach, besides cutting through this unstratified mass, has excavated its channel for a depth of several yards through the underlying porphyry, or at one point through a sandstone of the Lower Trias which occasionally appears in this region. The series of geological events of which we have evidence both in this ravine and in that of the Katzenbach, will be better understood by reference to the diagram, fig. 21. First a valley *a b c* was excavated in a country consisting almost entirely of red porphyry. Secondly, this

Fig. 21.

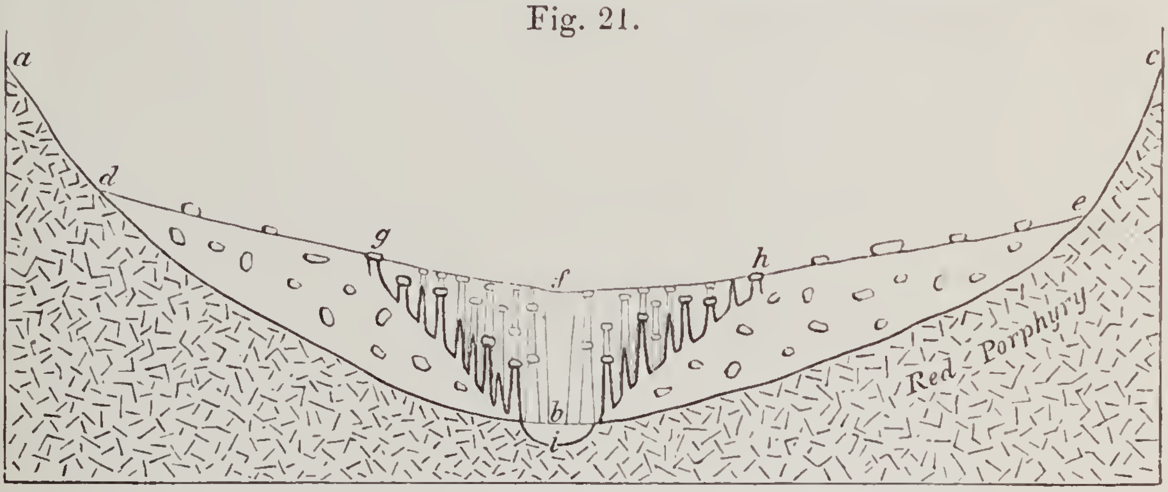


Diagram illustrative of the Formation of Earth-pillars.

a b c. Outline of original valley hollowed out of porphyry.
d b e d. Moraine left by glacier as it receded up the valley.
f. Chasm cut by torrent through the moraine before the first earth-pillars were formed.
b i. Channel of torrent excavated in porphyry below the level of the original valley.
g i h. Outline of the present valley, the earth-pillars marked by dark lines being still standing. The faint outlines between *g* and *h* represent portions of earth-pillars and their capping-stones now destroyed.

original valley was filled up in its lower part by moraine matter, *d b e d*, probably left by a large glacier as it retreated up the valley at the close of the Glacial period.

Thirdly, the chasm *f b* was cut out of this moraine by the Finsterbach, the red mud presenting a perpendicular face towards the chasm. This mud, which is very hard and solid when dry, becomes traversed by vertical cracks after having been moistened by rain and then dried by the sun. Those portions of the surface which are protected from the direct downward action of rain by a stone or erratic block, become gradually detached and isolated near the edge of the ravine, as in the case of the incipient columns at *g* and *h*. If the capping-stone be small, it soon falls off and the column terminates upwards in a point; but if it be large, sometimes several feet or yards in diameter, the column may acquire a great height, and, although tapering more and more in its upper portion where its sides have been longest exposed to the beating of the rain, it still continues to support the overhanging mass, which often looks as if poised on a point. Many of the fallen blocks, once the cappings of pillars which have disappeared, are now seen in the bed of the torrent, and their former position and the pillars on which they rested are expressed by the faint outlines given in the figure. The lower parts of some of these ancient columns still exist, because they have acquired new capping-stones by the weathering out at the surface of blocks originally buried at great depths in the moraine. Had the torrent ever risen during the long period required for the formation of the pillars, even a few yards above its present height, it would have swept away the lower columns, which are due therefore to pluvial action, not interfered with by fluviatile erosion.

If we ascend above *a* or *c*, to heights commanding a general view of the valley and moraine, the lateral terraces *d g* and *h e* look almost flat when contrasted with the precipitous cliffs *g i* and *h i*, for the latter slope at angles varying, as above stated, from 32° to 45°, whereas the terraces affording rich pastures and arable lands slope at angles varying from 10° to 16°. Here and there a large boulder or an angular erratic block is seen lying on the surface, as between *h* and *e*, which at some future time will probably become the head of a column. I measured one of the capping-stones on the left bank of the Finsterbach not far below the bridge, and

found it to be 10 feet in diameter, and the pillar which supports it 60 feet high. It seems to have owed its superior height to the large dimensions of the capping-stone, which has served as a shed to protect the indurated mud from the rain and sun. Near the edge of the cliff in the neighbourhood of this large column a wooden roof has been constructed to prevent that part of the terrace bordering the edge of the ravine along which the road passes from being split up into columns by the action of the sun and rain. The necessity of this shed attests the manner in which the denudation proceeds, and shows how its progress can be arrested. Some pillars on the Katzenbach have an elegant appearance, being perfectly round and vertically grooved or fluted. These grooves are caused by included stones which at different heights project slightly and give rise to an unequal rate of waste. In various instances such stones give origin to small lateral pillars, producing what may be called cluster columns. Both in the main valley and its tributaries the columns are arranged in rows, which descend from the edge of the terrace to the torrent, as represented between *h* and *i*; but between such parallel groups or rows are spaces devoid of columns and filled with wood, for the most part fir-trees, which form a picturesque background to the pillars when seen in profile. These intermediate spaces were probably all once occupied by columns, which have been undermined and swept away by occasional and temporary floods.

I was informed by Herr von Kaschnitz that in 1849, in cutting the road near the bridge over the Finsterbach, some trees and bushes being removed, the water was able to collect during heavy rains, and scoop out a small channel in the moraine matter, which it deepened yearly, until it undermined and removed, in the course of fifteen years, no less than twenty pillars or pyramids, and left in their place a straight empty gully which I saw, and which in the course of time will no doubt be filled with forest trees. The natural fall of trees or landslips may sometimes afford an opportunity for such torrential action to come into play. In the absence of this, or of an earthquake, the columns, which often take centuries to form, seem capable of enduring for ages.

I have stated that some of the stones in the pillars are glaciated, although the instances are rare, and I may add that the red porphyry at several points in the district called Ritten, where the earth-pillars occur, exhibits on its surface those dome-shaped protuberances called 'roches moutonnées,' confirming the theory of the former presence of glaciers in this district. The entire absence of shells, fluviatile or terrestrial, or of bones or any organic remains in the old moraines and pillars derived from them, supports the same view. But it may be asked why such remarkable columns are so seldom met with, seeing that glacier moraines, 'till' or boulder clays, are almost universal throughout a large part of the Alps, Scotland, Scandinavia, and North America. The fact is, that incipient and imperfect columns may be seen in many districts, but it happens that near Botzen the red porphyry has given rise, by its disintegration, to dense masses of mud of a peculiarly solid, homogeneous nature, weathering with a vertical face, and having in perfection every other requisite for making pillars, namely, first the absence of stratification which, when present, usually implies the unequal destructibility of different layers; and, secondly, the occurrence of numerous and often very large interspersed stones and blocks of rock.

Earth-pillars in the Canton of Valais in Switzerland.—Among many other examples of earth-pillars which I have seen in the Alps, some of the finest occur in the canton of Valais in Switzerland, though none of them form so striking a feature in the scenery as those near Botzen. Those at Stalden, in the valley of the Vispbach, are best known to tourists, and others occur near Useigne, between Sion and Evolena on the Borgne, another tributary of the Rhone, which, like the Visp, joins it on its southern or left bank.

The lower portions of both these valleys, like those of the Tyrol, before mentioned, have first been filled with moraine matter—in the case of the Borgne, more than 600 feet thick—and through the unstratified mass ravines have been cut by the action of the river, while rain has been active in widening their dimensions. In both cases the hardened mud, drift, or moraine matter, derived chiefly from the decom-

position of mica-schist, is of a whitish colour, but some included stones of serpentine, greenstone, and limestone, with surfaces distinctly glaciated, betray the glacier origin of the formation. The columns near Stalden on the Visp, about ten miles below Zermatt, were more numerous and beautiful in 1821 than they are now. This I ascertained by comparing their present condition with a drawing made in that year by Sir John Herschel. In July 1855 an earthquake inflicted much injury on the town of Visp, so that in passing through it three years afterwards, I saw rents still open in the walls of many of the houses. I then learnt that the same shock had thrown down a large part of one of the principal columns, which was 50 feet or more in height, and of which the capping-stone was 15 feet in diameter. The channel of the torrent, a small tributary of the Visp, had been deranged by landslips, and I observed that the active denudation which I saw beginning in 1857, had committed no small havoc among the pillars, in the eight years which intervened between that date and my second visit in 1865.

It is probable that few great valleys have been excavated in any part of the world, by rain and running water alone. During some part of their formation, subterranean movements have lent their aid in accelerating the process of erosion. Such movements being intermittent and often suspended for ages, and in many cases causing changes of level without any vibratory jar, their influence may easily be underrated or overlooked by geologists. At a lower point on the Visp-bach, half-way between the towns of Stalden and Visp, my guide pointed out to me, in 1857, a ferruginous spring near the right bank of the river, which had never been seen until 1855, when it was laid open by a landslip, which consisted of a great mass of drift, probably moraine matter belonging to the old river terrace. A powerful rill of water flowing from this spring had already in three years scooped out a gully, and eight years afterwards, in 1865, I found that it had cut its way much farther back, deepening and widening the small chasm, so that a vineyard which had been continuous before 1855 was then, in 1865, divided by a gap more than forty yards wide. This modern ravine was about fifteen feet deep

at its upper extremity, at an elevation of 200 feet above the Visp, and the depth increased gradually nearer the river. The shock of 1855 is believed to have shaken the Alps and the adjoining country over an area 300 miles long and 200 broad. We know not what changes of level it effected, whether the whole country was upheaved or sunk an inch, or a foot, or a yard by the event, or whether its position was unaltered. But we cannot doubt, that it is to a repetition of such movements reiterated throughout indefinite ages that we owe the very existence of land above the level of the sea. We may also be assured that the shape of every district, sometimes even the minor details of its topography, are to a certain extent modified by the same agency.

Fig. 22.

Dwarf's Tower (Zwergli-Thurm) near Viesch in the canton of Valais. From a sketch by Lady Lyell, taken Sept. 1857.*

Dwarf's Tower near Viesch.—In most of the valleys which communicate with the principal valley of the Rhone above the lake of Geneva, there is still a large remnant of that superficial drift and moraine matter which was left there at the close of the Glacial epoch. But even where we find no

* Avalanches had, in 1857, thrown down some trees, but the artist has removed others to produce the clearing here represented.

signs of the lateral valleys having been first filled up with drift to a certain height above their present streams, and then hollowed out again, it is probable that such denuding action has not been wanting. In favour of such an opinion, I may refer to two isolated stone-capped columns of hardened mud and gravel, which are to be seen in a pine forest near the village of Viesch, in a picturesque glen at the bottom of which flows a stream bearing the appropriate name of the Lawine Bach or 'Avalanche Brook.' The column which is here figured (fig. 22) occurs on the left side of the glen about 500 feet above the brook on a steep slope, the angle of which is about 45°. The fundamental rock consists of mica-schist. The height of the column is about 40 feet, its greatest diameter about 10 feet, and its irregular summit is capped by angular blocks of gneiss. Fragments of the same and of micaceous and talcose schist and pebbles of white quartz enter largely into the composition of 'the tower,' and many rocky fragments which may once have formed the capping-stones of other columns are everywhere strewed over the ground. There is a second similar pillar within 80 or 100 yards of the larger one, which is about half as high and capped by a single stone about 7 feet in diameter. The base of this smaller tower is at a higher level by about 60 feet than the summit of the larger one. I could detect no scratches or signs of glacial polishing on any of the stones which enter into the composition of these 'towers;' but this may perhaps be owing to the absence of limestone, serpentine, and greenstone rocks, which are much more favourable than gneiss for acquiring and retaining glacial markings. Avalanches of snow descend annually the steep slopes of this glen, with such force as frequently to uproot the largest pine-trees; and when we consider the destructive power of this cause and the earthquakes which have occurred again and again in the neighbourhood, we cannot but wonder that even two isolated columns have been spared to attest the former existence of a mass of matter which seems once to have levelled up the lower part of this narrow valley to a height of 500 or 600 feet above the channel of the present stream.

Action of rivers.—The pillars of Botzen before described

(p. 329), especially the tallest and most tapering of them, owe their formation to the force of separate raindrops, the water not having been able to collect into rills; but it is rarely possible to draw a clear line of demarcation between the action of

Fig. 23.

Ravine on the farm of Pomona, near Milledgeville, Georgia, as it appeared January 1846.

Excavated in twenty years, 55 feet deep, and 180 feet broad.

rain and that of running water. When travelling in Georgia and Alabama, in 1846, I saw in both these States the commencement of hundreds of valleys in places where the native forest had recently been removed. One of these newly formed gulleys or ravines is represented in the annexed woodcut,

from a drawing which I made on the spot. It occurs three miles and a half due west of Milledgeville, the capital of Georgia, and is situated on the farm of Pomona, on the direct road to Macon.*

In 1826, before the land was cleared, it had no existence; but when the trees of the forest were cut down, cracks three feet deep were caused by the sun's heat in the clay; and during the rains, a sudden rush of water through the principal crack deepened it at its lower extremity, from whence the excavating power worked backwards, till in the course of twenty years, a chasm measuring no less than 55 feet in depth, 300 yards in length, and varying in width from 20 to 180 feet, was the result. The high road has been several times turned to avoid this cavity, the enlargement of which is still proceeding, and the old line of road may be seen to have held its course directly over what is now the widest part of the ravine. In the perpendicular walls of this great chasm appear beds of clay and sand, red, white, yellow, and green, produced by the decomposition in situ of hornblendic gneiss with layers and veins of quartz, which remain entire to prove that the whole mass was once crystalline.

The termination of the cavity on the right hand in the foreground is the head or upper end of the ravine, and in almost every case, such gulleys are lengthened by the streams cutting their way backwards. The depth at the upper end is often, as in this case, considerable, and there is usually at this point, during floods, a small cascade.

I infer, from the rapidity of the denudation, which only began here after the removal of the native wood, that this spot, elevated about 600 feet above the sea, has been always covered with a dense forest, from the remote time when it first emerged from the sea.

It is, however, probable that when the granite and gneiss first rose above the waters, they consisted entirely of hard rock which had not yet been exposed to superficial decomposition and disintegration. Still we may conclude that the forest has been continuous from the time when the upper portion of these rocks began to be acted upon by rain, carbonic

* Lyell's Second Visit to the United States, 1846, vol. ii. p. 25.

acid, the winter's frost, the intense summer heat, and other causes. I could cite other regions in Georgia and Alabama where the cutting down of the trees, which had prevented the rain from collecting into torrents and running off in sudden land-floods, has given rise to recent ravines from 70 to 80 feet deep in Tertiary and Cretaceous formations.

Sinuosities of rivers.—In proportion as such valleys are widened, sinuosities are caused by the deflection of the stream first to one side and then to the other. The unequal hardness of the materials through which the channel is eroded tends partly to give new directions to the lateral force of excavation. When by these, or by accidental shiftings of the alluvial matter in the channel, the current is made to cross its general line of descent, it eats out a curve in the opposite bank, or in the side of the hills bounding the valley, from which curve it is turned back again at an equal angle, so that it recrosses the line of descent, and gradually hollows out another curve lower down in the opposite bank, till the whole sides of the valley, or river bed, present a succession of salient and retiring angles. Among the causes of deviation from a straight course by which torrents and rivers tend in mountainous regions to widen the valleys through which they flow may be mentioned the confluence of lateral torrents, swollen irregularly at different seasons by partial storms, and discharging at different times unequal quantities of sand, mud, and pebbles, into the main channel. The curves formed by the winding of rivers in their alluvial plains increase in magnitude in proportion to the volume of the rivers. Thus the Mississippi, about eighty miles north-west of New Orleans, near Port Hudson, makes a circuit of twenty-six miles and returns to within one mile of the point from which it set out; this occurred at Raccourci, which I visited in 1846,* and in the same year, immediately below the city of New Orleans, where the stream is about three-quarters of a mile wide, there was a bend of eighteen miles, after which the river came within five or six miles of the point from which it started. The extent of these curves depends on many conditions, especially on the nature and

* Second Visit to the United States, vol. ii. p. 193.

tenacity of the alluvial soil, often strengthened by the stems and roots of buried trees, and on the slope or fall of the river's bed.

When the tortuous flexures of a river are extremely great, the aberration from the direct line of descent may be restored by the river cutting through the isthmus which separates two neighbouring curves. Thus, in the annexed diagram, the extreme sinuosity of the river has caused it to return for a brief space in a contrary direction to its main course, so that

Fig. 25.

a peninsula is formed, and the isthmus (at *a*) is consumed on both sides by currents flowing in opposite directions. In this case an island is soon formed,—on either side of which a portion of the stream usually remains.

Transporting power of water.—In regard to the transporting power of water, we may often be surprised at the facility with which streams of a small size, and descending a slight declivity, bear along coarse sand and gravel; for we usually estimate the weight of rocks in air, and do not reflect on their comparative buoyancy when submerged in a denser fluid. The specific gravity of many rocks is not more than twice that of water, and very rarely more than thrice, so that almost all the fragments propelled by a stream have lost a third, and many of them half, of what we usually term their weight.

It has been proved by experiments, in contradiction to the theories of the earlier writers on hydrostatics, to be a universal law, regulating the motion of running water, that the velocity at the bottom of the stream is everywhere less than in any part above it, and is greatest at the surface. Also, that the superficial particles in the middle of the stream move more swiftly than those at the sides. This retardation of the lowest and lateral currents is produced by friction; and when the velocity is sufficiently great, the soil

composing the sides and bottom gives way. A velocity of three inches per second at the bottom is stated to be sufficient to tear up fine clay,—six inches per second, fine sand,—twelve inches per second, fine gravel,—and three feet per second, stones of the size of an egg.* Mr. Jamieson has remarked† that if the pebbly bed of a rapidly flowing river be examined, it will be found that the pebbles have a tendency to arrange themselves in the position shown in fig. 25, which is probably

Fig. 25.

that of greatest resistance to the stream. Some sections of recent gravel in the bed of the river Dee display this arrangement, showing that the gravel had been lodged by a rapid current of water flowing down the valley.

Those peculiar inequalities or ridges on the surface of sand or sandstone which are called ripple-marks arise from the unequal force of the current by which the particles of sand are drifted along the bottom. The ridges are at right angles to the impelling force, and are steepest on their leeward side. They are formed equally by currents of wind (as on sand dunes), and under water, usually at slight depths. The following is the manner in which I once observed the motion of the air to produce this effect on a large extent of level beach, exposed at low tide near Calais. Clouds of fine white sand were blown from the neighbouring dunes, so as to cover the shore and whiten a dark level surface of sandy mud, and this fresh covering of sand was beautifully rippled. On levelling all the small ridges and furrows of this ripple over an area of several yards square, I saw them perfectly restored in about ten minutes, the general direction of the ridges being always at right angles to that of the wind. The restoration began by the appearance here and there of small detached heaps of sand, which soon lengthened and joined together, so as to form long sinuous ridges with intervening furrows. Each ridge had one side slightly inclined, and the other steep;

* Encyc. Brit. art. 'Rivers.' † Quart. Geol. Journ. vol. xvi. p. 349.

the lee side being always steep, as *b, c,—d, e*; the windward side a gentle slope, as *a, b,—c, d*, fig. 26. When a gust of wind blew with sufficient force to drive along a cloud of sand, all the ridges were seen to be in motion at once, each encroaching on the furrow before it, and, in the course of a few minutes, filling the place which the furrows had occupied. The mode of advance was by the continual drifting of grains of sand up the slopes *a b* and *c d*, which grains, when they arrived at *b* and *d*, fell over the scarps *b c* and *d e*, and were under shelter from the wind; so that they remained stationary, resting, according to their shape and momentum, on different parts of the descent, and a few only rolling to the bottom. In this manner each ridge was distinctly seen to move slowly on as often as the force of the wind augmented. Occasionally part of a ridge, advancing more rapidly than the rest, overtook the ridge immediately before it and became confounded with it, thus causing those bifurcations and

Fig. 26.

branches which are so common on the surface of sandstones of all ages. In such sandstones, as well as now on the sea-coast at low tide, we may often detect two systems of ripples interfering with each other; one more ancient and half effaced, and a newer one, in which the grooves and ridges are more distinct, and in a different direction. This crossing of two sets of ripples arises from a change in the direction of the tidal or other current, or of the wind.

It should be borne in mind that running water derives its power of rounding off the angles of hard rocks and of undermining cliffs, by setting in motion much sand, fine and coarse, and gravel, which it throws against every obstacle lying in its way. The force thus acquired by torrents in mountainous regions is more easily understood; but a question naturally arises, how the more tranquil rivers of the valleys and plains, flowing on comparatively level ground, can remove the prodigious burden which is discharged into them by their

numerous tributaries, and by what means they are enabled to convey the whole mass to the sea? If they had not this removing power, their channels would be annually choked up, and the valleys of the lower country, and plains at the base of mountain-chains, would be continually strewed over with fragments of rock and sterile sand. But this evil is prevented by a general law regulating the conduct of running water,—that two equal streams do not, when united, occupy a bed of double surface. Nay, the width of the principal river, after the junction of a tributary, sometimes remains the same as before, or is even lessened. The cause of this apparent paradox was long ago explained by the Italian writers who had studied the confluence of the Po and its feeders in the plains of Lombardy.

The addition of a smaller river augments the velocity of the main stream, often in the same proportion as it does the quantity of water. The cause of the greater velocity is, first, that after the union of two rivers the water, in place of the friction of four banks, has only that of two to surmount; 2dly, because the main body of the stream, being farther distant from the banks, flows on with less interruption; and lastly, because a greater quantity of water moving more swiftly, digs deeper into the river's bed. By this beautiful adjustment, the water which drains the interior country is made continually to occupy less room as it approaches the sea; and thus the most valuable part of our continents, the rich deltas and great alluvial plains, are prevented from being constantly under water.

River floods in Scotland, 1829.—Many remarkable illustrations of the power of running water in moving stones and heavy material were afforded by the storm and floods which occurred on the 3rd and 4th of August 1829 in Aberdeenshire and other counties in Scotland. The elements during this storm assumed all the characters which mark the tropical hurricanes; the wind blowing in sudden gusts and whirlwinds, the lightning and thunder being such as are rarely witnessed in our climate, and heavy rain falling without intermission. The floods extended almost simultaneously, and with equal violence, over that part of the north-

east of Scotland which would be cut off by two lines drawn from the head of Loch Rannoch (lat. 56·40 N., long. 4·26 W.), one towards Inverness and the other to Stonehaven. The united line of the different rivers which were flooded could not be less than from five to six hundred miles in length; and their courses were marked throughout by the destruction of bridges, roads, crops, and buildings. Sir T. D. Lauder has recorded the destruction of thirty-eight bridges, and the entire obliteration of a great number of farms and hamlets. On the Nairn, a fragment of sandstone, fourteen feet long by three feet wide and one foot thick, was carried above 200 yards down the river. Some new ravines were formed on the sides of mountains where no streams had previously flowed, and ancient river channels, which had never been filled from time immemorial, gave passage to a copious flood.*

The bridge over the Dee at Ballater consisted of five arches, having upon the whole a water-way of 260 feet. The bed of the river, on which the piers rested, was composed of rolled pieces of granite and gneiss. The bridge was built of granite, and had stood uninjured for twenty years; but the different parts were swept away in succession by the flood, and the whole mass of masonry disappeared in the bed of the river. 'The river Don,' observes Mr. Farquharson, in his account of the inundations, 'has upon my own premises forced a mass of four or five hundred tons of stones, many of them two or three hundred pounds' weight, up an inclined plane, rising six feet in eight or ten yards, and left them in a rectangular heap, about three feet deep, on a flat ground:—the heap ends abruptly at its lower extremity.' †

The power even of a small rivulet, when swollen by rain, in removing heavy bodies, was exemplified in August 1827, in the College, a small stream which flows down a slight declivity from the eastern water-shed of the Cheviot Hills. Several thousand tons' weight of gravel and sand were transported to the plain of the Till, and a bridge, then in

* Sir T. D. Lauder's Account of the Great Floods in Morayshire, August 1829.

† Quarterly Journ. of Sci., &c. No. xiii. New Series, p. 331.

progress of building, was carried away, some of the arch-stones of which, weighing from half to three-quarters of a ton each, were propelled two miles down the rivulet. On the same occasion, the current tore away from the abutment of a mill-dam a large block of greenstone-porphyry, weighing nearly two tons, and transported it to the distance of a quarter of a mile. Instances are related as occurring repeatedly, in which from one to three thousand tons of gravel are, in like manner, removed by this streamlet to still greater distances in one day.*

Floods caused by landslips, 1826.—The power which running water may exert, in the lapse of ages, in widening and deepening a valley, does not so much depend on the volume and velocity of the stream usually flowing in it, as on the number and magnitude of the obstructions which have, at different periods, opposed its free passage. If a torrent, however small, be effectually dammed up, the size of the valley above the temporary barrier, and its declivity below, and not the dimensions of the torrent, will determine the violence of the débâcle. The most universal source of local deluges are landslips, slides, or avalanches, as they are sometimes called, when great masses of rock and soil, or in some cases ice and snow, are precipitated into the bed of a river, the boundary cliffs of which have been thrown down by the shock of an earthquake, or undermined by springs or other causes. Volumes might be filled with the enumeration of instances on record of these terrific catastrophes; I shall therefore select a few examples derived from regions which I have myself visited.

Two dry seasons in the White Mountains, in New Hampshire (United States), were followed by heavy rains on the 28th August 1826, when from the steep and lofty acclivities which rise abruptly on both sides of the river Saco, innumerable rocks and stones, many of sufficient size to fill a common apartment, were detached, and in their descent swept down before them, in one promiscuous and frightful ruin, forests, shrubs, and the earth which sustained them. Although there are numerous indications on the steep sides of these hills of

* Culley, Proceed. Geol. Soc. 1829.

former slides of the same kind, yet no tradition had been handed down of any similar catastrophe within the memory of man, and the growth of the forest on the very spots now devastated clearly showed that for a long interval nothing similar had occurred. One of these moving masses was afterwards found to have slid three miles, with an average breadth of a quarter of a mile. The natural excavations commenced generally in a trench a few yards in depth and a few rods in width, and descended the mountains, widening and deepening till they became vast chasms. At the base of these hollow ravines was seen a confused mass of ruins, consisting of transported earth, gravel, rocks, and trees. Forests of spruce-fir and hemlock, a kind of fir somewhat resembling our yew in foliage, were prostrated with as much ease as if they had been fields of grain; for where they disputed the ground, the torrent of mud and rock accumulated behind, till it gathered sufficient force to burst the temporary barrier.

The valleys of the Amonoosuck and Saco presented for many miles an uninterrupted scene of desolation, all the bridges being carried away, as well as those over the tributary streams. In some places, the road was excavated to the depth of from fifteen to twenty feet; in others it was covered with earth, rocks, and trees, to as great a height. The water flowed for many weeks after the flood, as densely charged with earth as it could be without being changed into mud, and marks were seen in various localities of its having risen on either side of the valley to more than twenty-five feet above its ordinary level. Many sheep and cattle were swept away, and the Willey family, nine in number, who in alarm had deserted their house, were destroyed on the banks of the Saco; seven of their mangled bodies were afterwards found near the river, buried beneath drift-wood and mountain ruins.* Eleven years after the event, the deep channels worn by the avalanches of mud and stone, and the immense heaps of boulders and blocks of granite in the river channel, still formed, says Professor Hubbard, a picturesque feature in the scenery.†

When I visited the country in 1845, eight years after

* Silliman's Journal, vol. xv. No. 2, p. 216. Jan. 1829.
† Ibid. vol. xxxiv. p. 115.

Professor Hubbard, I found the signs of devastation still very striking; I also particularly remarked that, although the surface of the bare granitic rocks had been smoothed by the passage over them of so much mud and stone, there were no continuous parallel and rectilinear furrows, nor any of the fine scratches or striæ which characterise *glacial* action. The absence of these is nowhere more clearly exemplified than in the bare rocks over which passed the great 'Willey slide' of 1826.*

But the catastrophes in the White Mountains are insignificant, when compared to those which are occasioned by earthquakes, when the boundary hills, for miles in length, are thrown down into the hollow of a valley. I shall have opportunities of alluding to inundations of this kind when treating expressly of earthquakes, and shall content myself at present with selecting an example of a flood due to a different cause.

Flood in the valley of Bagnes, 1818.—The valley of Bagnes is one of the largest of the lateral embranchments of the main valley of the Rhone, above the Lake of Geneva. Its upper portion was, in 1818, converted into a lake by the damming up of a narrow pass, by avalanches of snow and ice, precipitated from an elevated glacier into the bed of the river Dranse. In the winter season, during continued frost, scarcely any water flows in the bed of this river to preserve an open channel, so that the ice barrier remained entire until the melting of the snow in spring, when a lake was formed above, about half a league in length, which finally attained in some parts a depth of about 200 feet, and a width of about 700 feet. To prevent or lessen the mischief apprehended from the sudden bursting of the barrier, an artificial gallery, 700 feet in length, was cut through the ice, before the water had risen to a great height. When at last it reached such an elevation as to flow through the tunnel, it dissolved the ice, and thus deepened its channel, until nearly half of the whole contents of the lake were slowly drained off. But at length, on the approach of the hot season, the central portion of the remaining mass of ice gave way with a tremendous crash, and the residue of the lake was

* See Lyell's Second Visit to the United States, vol. i. p. 69.

emptied in half an hour. In the course of their descent, the waters encountered several narrow gorges, and at each of these they rose to a great height, and then burst with new violence into the next basin, sweeping along rocks, forests, houses, bridges, and cultivated land. For the greater part of its course the flood resembled a moving mass of rock and mud, rather than of water. Some fragments of granitic rocks, of enormous magnitude, and which from their dimensions, might be compared without exaggeration to houses, were torn out of a more ancient alluvium, and borne down for a quarter of a mile. One of the fragments moved was sixty paces in circumference.* The velocity of the water, in the first part of its course, was thirty-three feet per second, which diminished to six feet before it reached the Lake of Geneva, where it arrived in six hours and a half, the distance being 45 miles.†

This flood left behind it, on the plains of Martigny, thousands of trees torn up by the roots, together with the ruins of buildings. Some of the houses in that town were filled with mud up to the second story. After expanding in the plain of Martigny, it entered the Rhone, and did no further damage; but some bodies of men, who had been drowned above Martigny, were afterwards found, at the distance of about thirty miles, floating on the farther side of the Lake of Geneva, near Vevay.

The waters, on escaping from the temporary lake, intermixed with mud and rock, swept along for the first four miles at the rate of above twenty miles an hour; and M. Escher, the engineer, calculated that the flood furnished 300,000 cubic feet of water every second—an efflux which is five times greater than that of the Rhine below Basle. Now if part of the lake had not been gradually drained off, the flood would have been nearly double, approaching in volume to some of the largest rivers in Europe. It is evident, therefore, that, when we are speculating on the excavating force which a river may have exerted in any particular valley, the most important

* This block was measured by Capt. B. Hall, R.N.

† Inundation of the Val de Bagnes, in 1818, Ed. Phil. Journ., vol. i. p. 187, from Memoir of M. Escher.

question is, not the volume of the existing stream, nor the present levels of its channel, nor even the nature of the rocks, but the probability of a succession of floods at some period since the time when the valley may have been first elevated above the sea.

For several months after the débâcle of 1818, the Dranse, having no settled channel, shifted its position continually from one side to the other of the valley, carrying away newly erected bridges, undermining houses, and continuing to be charged with as large a quantity of earthy matter as the fluid could hold in suspension. I visited this valley four months after the flood, and was witness to the sweeping away of a bridge, and the undermining of part of a house. The greater part of the ice-barrier was then standing, presenting vertical cliffs 150 feet high, like ravines in the lava-currents of Etna or Auvergne, where they are intersected by rivers.

Inundations, precisely similar, are recorded to have occurred at former periods in this district, and from the same cause. In 1595, for example, a lake burst, and the waters, descending with irresistible fury, destroyed the town of Martigny, where from sixty to eighty persons perished. In a similar flood, fifty years before, 140 persons were drowned.

Flood at Tivoli, 1826.—I shall conclude with one more example derived from a land of classic recollections, the ancient Tibur, and which, like all the other inundations above alluded to, occurred within the present century. The younger Pliny, it will be remembered, describes a flood on the Anio, which destroyed woods, rocks, and houses, with the most sumptuous villas and works of art.* Often for four or five centuries consecutively, this 'headlong stream,' as Horace truly called it, has remained within its bounds, and then, after so long an interval of rest, has at different periods inundated its banks again, and widened its channel. The last of these catastrophes happened 15th Nov. 1826, after excessively heavy rains, and a lively description of the event was given to me by eye-witnesses when I visited the spot in 1829. The waters appear to have been impeded by an artificial dike, by which they were separated into two parts,

* Lib. viii. Epist. 17.

a short distance above Tivoli. They broke through this dike; and, leaving the left trench dry, precipitated themselves, with their whole weight, on the right side. Here they undermined, in the course of a few hours, a high cliff, and widened the river's channel about fifteen paces. On this stood the church of St. Lucia, and about thirty-six houses of the town of Tivoli, which were all carried away, presenting, as they sank into the roaring flood, a terrific scene of destruction to the spectators on the opposite bank. As the foundations were gradually removed, buildings, some of them edifices of considerable height, were first traversed with numerous rents, which soon widened into large fissures, until at length the roofs fell in with a crash, and then the walls sank into the river, and were hurled down the cataract below.

The destroying agency of the flood came within two hundred yards of the precipice on which the beautiful temple of Vesta stands; but fortunately this precious relic of antiquity was spared, while the wreck of modern structures was hurled down the abyss. Vesta, it will be remembered, in the heathen mythology, personified the stability of the earth; and when the Samian astronomer, Aristarchus, first taught that the earth revolved on its axis, and round the sun, he was publicly accused of impiety, for 'moving the everlasting Vesta from her place.' Playfair observed, that when Hutton ascribed instability to the earth's surface, and represented the continents which we inhabit as the theatre of incessant change and movement, his antagonists, who regarded them as unalterable, assailed him in a similar manner with accusations founded on religious prejudices.* We might appeal to the excavating power of the Anio as corroborative of one of the most controverted parts of the Huttonian theory; and if the days of omens had not gone by, the geologists who now worship Vesta might regard the catastrophe as portentous. We may, at least, recommend the modern votaries of the goddess to lose no time in making a pilgrimage to her shrine, for the next flood may not respect the temple.

Excavation of rocks by running water.—The rapidity with which even the smallest streams hollow out deep channels in

* Illustr. of Hutt. Theory, § 3, p. 147.

soft and destructible soils is remarkably exemplified in volcanic countries, where the sand and half-consolidated tuffs oppose but a slight resistance to the torrents which descend the mountain-side. After the heavy rains which followed the eruption of Vesuvius in 1824, the water flowing from the Atrio del Cavallo cut, in three days, a new chasm through strata of tuff and ejected volcanic matter, to the depth of twenty-five feet. I found the old mule road, in 1828, intersected by this new ravine.

But deep chasms may be gradually eroded through the hardest rock, by running water, charged with foreign matter. Good illustrations of this phenomenon may be seen in many valleys in Central France where the channels of rivers have been barred up by solid currents of lava, through which the streams have re-excavated a passage, often of great width and from twenty to seventy feet in depth. In these cases there are decisive proofs that neither the sea, nor any denuding wave or extraordinary body of water, has passed over the spot since the melted lava was consolidated. Every hypothesis of the intervention of sudden and violent agency is entirely excluded, because the cones of *loose* scoriæ, out of which the lavas flowed, are oftentimes at no great elevation above the rivers, and have remained undisturbed during the whole period which has been sufficient for the hollowing out of such enormous ravines.

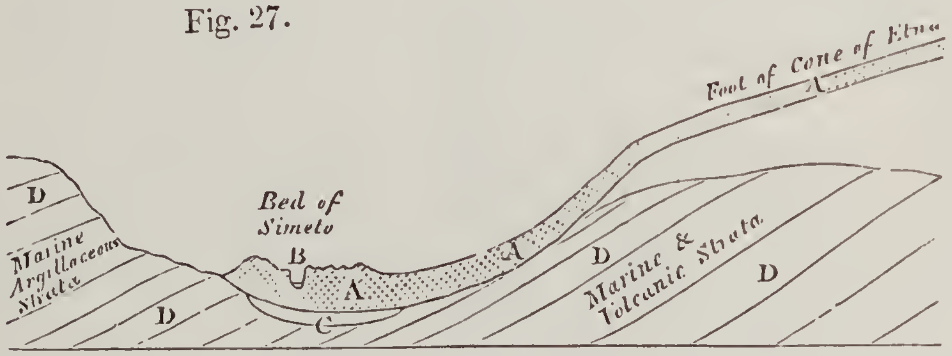
Recent excavation by the Simeto.—At the western base of Etna, a current of lava (A A, fig. 27), descending from near the summit of the great volcano, has flowed to the distance of five or six miles, and then reached the alluvial plain of the Simeto, the largest of the Sicilian rivers, which skirts the base of Etna, and falls into the sea a few miles south of Catania. The lava entered the river about three miles above the town of Aderno, and not only occupied its channel for some distance, but, crossing to the opposite side of the valley, accumulated there in a rocky mass. Gemmellaro gives the year 1603 as the date of the eruption.* The appearance of the current clearly proves that it is one of the most modern of those of Etna; for it has not been covered or crossed by

* Quadro Istorico dell' Etna, 1824.

subsequent streams or ejections, and the olive-trees which had been planted on its surface were all of small size when I examined the spot in 1828, yet they were all older than the natural wood on the same lava. In the course, therefore, of about two centuries, the Simeto has eroded a passage from fifty to several hundred feet wide, and in some parts from forty to fifty feet deep.

The portion of lava cut through is in no part porous or scoriaceous, but consists of a compact homogeneous mass of hard blue rock, somewhat inferior in weight to ordinary basalt, and containing crystals of olivine and glassy felspar. The general declivity of this part of the bed of the Simeto is not considerable; but, in consequence of the unequal waste of the lava, two waterfalls occur at Passo Manzanelli,

Fig. 27.



Recent excavation of lava at the foot of Etna by the river Simeto.

each about six feet in height. Here the chasm (B, fig. 27) is about forty feet deep, and only fifty broad.

The sand and pebbles in the river-bed consist chiefly of a brown quartzose sandstone, derived from the upper country; but the materials of the volcanic rock itself must have greatly assisted the attrition. This river, like the Caltabiano on the eastern side of Etna, has not yet cut down to the ancient bed of which it was dispossessed, and of which the probable position is indicated in the above diagram (C, fig. 27).

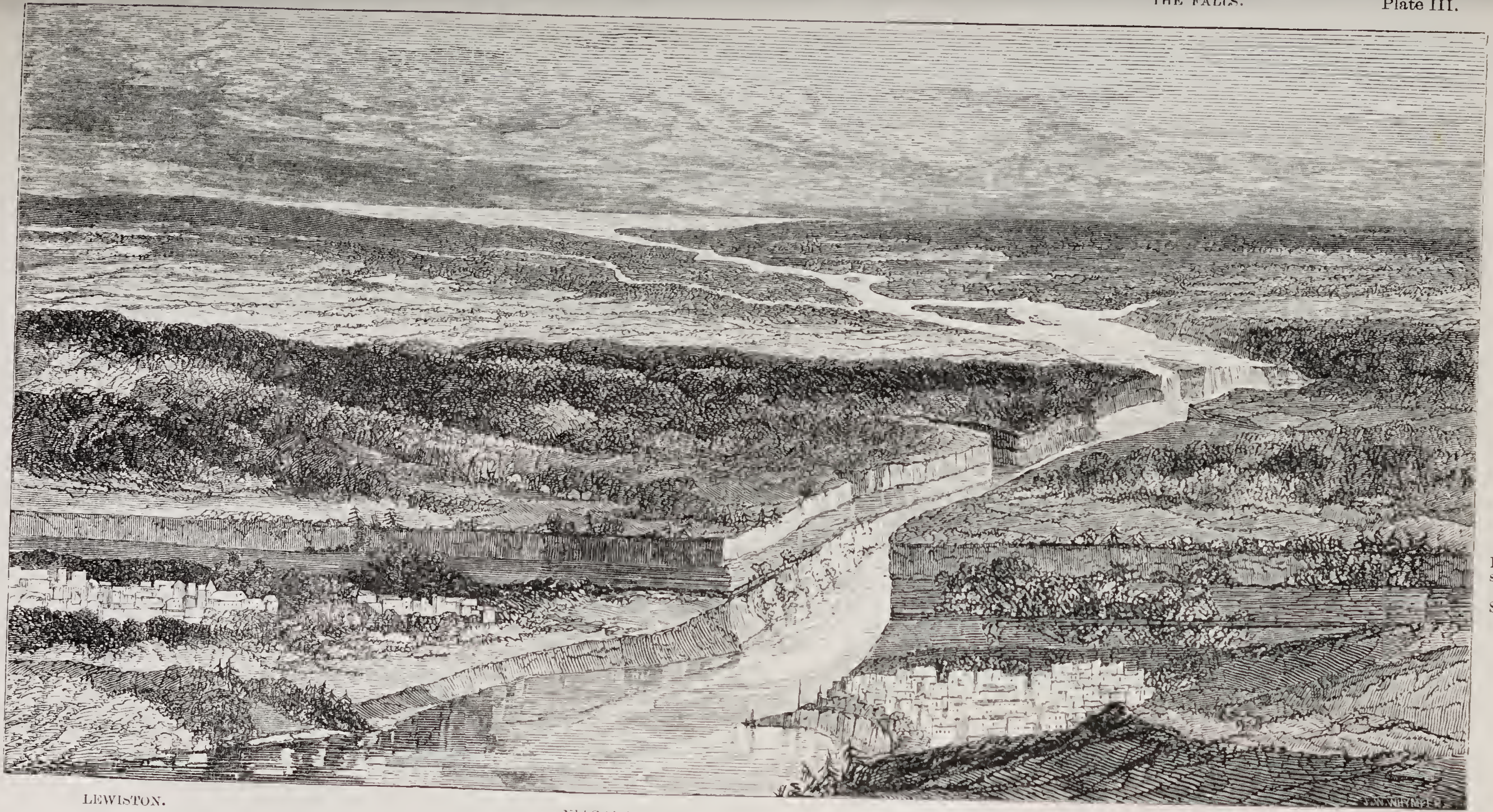
On entering the narrow ravine where the water foams down the two cataracts, we are entirely shut out from all view of the surrounding country; and a geologist who is accustomed to associate the characteristic features of the landscape with the relative age of certain rocks, can scarcely

dissuade himself from the belief that he is contemplating a scene in some rocky gorge of very ancient date. The external forms of the hard blue lava are as massive as any of the oldest trap-rocks of Scotland. The solid surface is in some parts smoothed and almost polished by attrition, and covered in others with a light-coloured lichen, which imparts to it an air of antiquity, which greatly heightens the delusion. But the moment we re-ascend the cliff the spell is broken ; for we scarcely recede a few paces, before the ravine and river disappear, and we stand on the black and rugged surface of a vast current of lava, which seems unbroken, and which we can trace up nearly to the distant summit of that majestic cone which Pindar called the 'pillar of heaven,' and which still continues to send forth a fleecy wreath of vapour, reminding us that its fires are not extinct, and that it may again give out a rocky stream, wherein other scenes like that now described may present themselves to future observers.

Falls of Niagara.—The falls of Niagara afford a magnificent example of the progressive excavation of a deep valley in solid rock. That river flows over an elevated table-land, in which the basin of Lake Erie forms a depression. Where the river issues from the lake, it is nearly a mile in width, and 330 feet above the level of Lake Ontario, which is about thirty miles distant. For the first fifteen miles below Lake Erie the surrounding country, comprising Upper Canada on the west, and the state of New York on the east, is almost on a level with its banks, and nowhere more than thirty or forty feet above them.* (See Plate III.) The river being occasionally interspersed with low wooded islands, and having sometimes a width of three miles, glides along at first with a clear, smooth, and tranquil current, falling only fifteen feet in as many miles, and in this part of its course resembling an arm

* The reader will find in my Travel in North America, vol. i. ch. 2, a coloured geological map and section of the Niagara district, also a bird's-eye view of the Falls and adjacent country, coloured geologically, of which the first idea was suggested by the excellent original sketch given by Mr. Bakewell. I have referred more fully to these and to Mr. Hall's Report on the Geology of New York, as well as to the earlier writings of Hennepin and Kalm in the same work, and have speculated on the origin of the escarpment over which the falls may have been originally precipitated. Vol. i. p. 32, and vol. ii. p. 93.

Plate III.



Ideal bird's-eye view of the course of the Niagara River from Lake Erie to Queenstown (showing the ravine cut by the river between Queenstown and the Falls.) See p. 354.

of Lake Erie. But its character is afterwards entirely changed, on approaching the Rapids, where it begins to rush and foam over a rocky and uneven limestone bottom, for the space of nearly a mile, till at length it is thrown down perpendicularly 165 feet at the Falls. Here the river is divided into two sheets of water by an island called Goat Island, the larger cataract being more than a third of a mile broad, the smaller one having a breadth of 600 feet. When the water has precipitated itself into a pool of vast depth, it rushes with great velocity down the sloping bottom of a narrow chasm, for a distance of seven miles. This ravine varies from 200 to 400 yards in width from cliff to cliff; contrasting, therefore, strongly in its breadth with that of the river above. Its depth is from 200 to 300 feet, and it intersects for about seven miles the table-land before described, which terminates suddenly at Queenstown in an escarpment or long line of inland cliff facing northwards, towards Lake Ontario. The Niagara, on reaching the escarpment and issuing from the gorge, enters the flat country, which is so nearly on a level with Lake Ontario, that there is only a fall of about four feet in the seven additional miles which intervene between Queenstown and the shores of that lake.

It has long been the popular belief that the Niagara once flowed in a shallow valley across the whole platform, from the present site of the Falls to the escarpment (called the Queenstown Heights), where it is supposed that the cataract was first situated, and that the river has been slowly eating its way backwards through the rocks for the distance of seven miles. This hypothesis naturally suggests itself to every observer, who sees the narrowness of the gorge at its termination, and throughout its whole course, as far up as the Falls, above which point the river expands as before stated. The boundary cliffs of the ravine are usually perpendicular, and in many places undermined on one side by the impetuous stream. The uppermost rock of the table-land at the Falls consists of hard limestone (a member of the Silurian series), about ninety feet thick, beneath which lie soft shales of equal thickness, continually undermined by the action of the spray, which rises from the pool into which so large a

body of water is projected, and is driven violently by gusts of wind against the base of the precipice. In consequence of this action, and that of frost, the shale disintegrates and crumbles away, and portions of the incumbent rock overhang forty feet, and often when unsupported tumble down, so that the Falls do not remain absolutely stationary at the same spot, even for half a century. Accounts have come down to us, from the earliest period of observation, of the frequent destruction of these rocks, and the sudden descent of huge fragments in 1818 and 1828 is said to have shaken the adjacent country like an earthquake. The earliest travellers, Hennepin and Kalm, who in 1678 and 1751 visited the Falls, and published views of them, attest the fact, that the rocks have been suffering from dilapidation for more than a century and a half, and that some slight changes, even in the scenery of the cataract, have been brought about within that time. The idea, therefore, of perpetual and progressive waste is constantly present to the mind of every beholder; and as that part of the chasm, which has been the work of the last 150 years, resembles precisely in depth, width, and character the rest of the gorge which extends seven miles below, it is most natural to infer, that the entire ravine has been hollowed out in the same manner, by the recession of the cataract.

It must at least be conceded, that the river supplies an adequate cause for executing the whole task thus assigned to it, provided we grant sufficient time for its completion; but, as this part of the country was a wilderness till near the end of the last century, we can obtain no accurate data for estimating the exact rate at which the cataract has been receding. Mr. Bakewell, son of the eminent geologist of that name, who visited Niagara in 1829, made the first attempt to calculate, from the observations of one who had lived forty years at the Falls, and who had been the first settler there, that the cataract had during that period gone back about a yard annually. But after the most careful enquiries which I was able to make, during my visit to the spot in 1841-2, I came to the conclusion that the average of one foot a year would be a much more probable conjecture. In that case, it would have required 35,000 years for the

retreat of the Falls, from the escarpment of Queenstown to their present site. It seems by no means improbable that such a result would be no exaggeration of the truth, although we cannot assume that the retrograde movement has been uniform. An examination of the geological structure of the district, as laid open in the ravine, shows that at every step in the process of excavation, the height of the precipice, the hardness of the materials at its base, and the quantity of fallen matter to be removed, must have varied. At some points it may have receded much faster than at present, but in general its progress was probably slower, because the cataract, when it began to recede, must have had nearly twice its present height, and therefore twice the quantity of rock to remove.

From observations made by me in 1841, when I had the advantage of being accompanied by Mr. Hall, State geologist of New York, and in 1842, when I re-examined the Niagara district, I obtained geological evidence of the former existence of an old river-bed, which, I have no doubt, indicates the original channel through which the waters once flowed from the Falls to Queenstown, at the height of nearly 300 feet above the bottom of the present gorge. The geological monuments alluded to consist of patches of sand and gravel, forty feet thick, containing fluviatile shells of the genera Unio, Cyclas, Melania, &c., such as now inhabit the waters of the Niagara above the Falls. The identity of the fossil species with the recent is unquestionable, although bones of the extinct mastodon (*M. giganteus*) are associated with the same in Goat Island. These fresh-water deposits occur at several points along the cliffs bounding the ravine, so that they prove the former extension of an elevated shallow valley, four miles below the Falls, a distinct prolongation of that now occupied by the Niagara, in the elevated region intervening between Lake Erie and the Falls. Whatever theory be framed for the hollowing out of the ravine further down, or for the three miles which intervene between the whirlpool and Queenstown, it will always be necessary to suppose the former existence of a barrier of *rock*, not of loose and destructible materials, such as those composing the

drift in this district, somewhere immediately below the whirlpool. By that barrier the waters were held back for ages, when the fluviatile deposit, forty feet in thickness, and 250 feet above the present channel of the river, originated. If we are led by this evidence to admit that the cataract has cut back its way for four miles, we can have little hesitation in referring the excavation of the remaining three miles below to a like agency, the shape of the chasm being precisely similar.

There have been many speculations respecting the future recession of the Falls, and the deluge that might be occasioned by the sudden escape of the waters of Lake Erie, if the ravine should ever be prolonged sixteen miles backwards. But a more accurate knowledge of the geological succession of the rocks, brought to light by the State Survey, has satisfied every geologist that the Falls would diminish gradually in height before they travelled back two miles, and in consequence of a gentle dip of the strata to the south, the massive limestone now at the top would then be at their base, and would retard, and perhaps put an effectual stop to, the excavating process.*

* Since I visited the Falls I have repeatedly seen in the American newspapers accounts of changes caused in the outline of the cataract by the wearing away of the channel and the undermining of huge fragments of rock, which have been precipitated into the chasm below. Some of these alterations have rendered it impossible to reach a spot under the sheet of falling water to which I was led by my guide in 1841.

CHAPTER XVI.

TRANSPORTATION OF SOLID MATTER BY ICE.

CARRYING POWER OF RIVER-ICE—ROCKS ANNUALLY CONVEYED INTO THE ST. LAWRENCE BY ITS TRIBUTARIES—GROUND-ICE; ITS ORIGIN AND TRANSPORTING POWER—GLACIERS—THEORY OF THEIR DOWNWARD MOVEMENT—SMOOTHED AND GROOVED ROCKS—THE MORAINE UNSTRATIFIED—TERRACE OR BEACH FORMED BY A GLACIER-LAKE IN SWITZERLAND—ICEBERGS COVERED WITH MUD AND STONES—LIMITS OF GLACIERS AND ICEBERGS—THEIR EFFECTS ON THE BOTTOM WHEN THEY RUN AGROUND—PACKING OF COAST-ICE—BOULDERS DRIFTED BY ICE ON COAST OF LABRADOR—BLOCKS MOVED BY ICE IN THE BALTIC.

THE power of running water to carry sand, gravel, and fragments of rock to considerable distances is greatly augmented in those regions where, during some part of the year, the frost is of sufficient intensity to convert the water, either at the surface or bottom of rivers, into ice.

This subject may be considered under three different heads:—first, the effect of surface-ice and ground-ice, in enabling streams to remove gravel and stones to a distance; secondly, the action of glaciers in the transport of boulders, and in the polishing and scratching of rocks; thirdly, the floating off of portions of glaciers charged with solid matter, as icebergs, into the sea, and the drifting of coast-ice.

River-ice.—Pebbles and small pieces of rock may be seen entangled in ice, and floating annually down the Tay in Scotland, as far as the mouth of that river. Similar observations might doubtless be made respecting almost all the larger rivers of England and Scotland; but there seems reason to suspect that the principal transfer from place to place of pebbles and stones adhering to ice goes on unseen by us under water. For although the specific gravity of the compound mass may cause it to sink, it may still be very

buoyant, and easily borne along by a feeble current. The ice, moreover, melts very slowly at the bottom of running streams in winter, as the water there is often nearly at the freezing point, as will be seen from what will be said in the sequel of ground-ice.

As we travel eastward in Europe in the latitudes of Great Britain, we find the winters more severe, and the rivers more regularly frozen over. M. Lariviere relates that, being at Memel on the Baltic in 1821, when the ice of the river Niemen broke up, he saw a mass of ice thirty feet long which had descended the stream, and had been thrown ashore. In the middle of it was a triangular piece of granite, about a yard in diameter, resembling in composition the red granite of Finland.*

When rivers in the northern hemisphere flow from south to north, the ice first breaks up in the higher part of their course, and the flooded waters, bearing along large icy fragments, often arrive at parts of the stream which are still firmly frozen over. Great inundations are thus frequently occasioned by the obstructions thrown in the way of the descending waters, as in the case of the Mackenzie in North America, and the Irtish, Obi, Yenesei, Lena, and other rivers of Siberia. (See map, fig. 7, p. 180.) A partial stoppage of this kind occurred Jan. 31, 1840, in the Vistula, about a mile and a half above the city of Dantzic, where the river, choked up by packed ice, was made to take a new course over its right bank, so that it hollowed out in a few days a deep and broad channel, many leagues in length, through a tract of sand-hills which were from 40 to 60 feet high.

In Canada, where the winter's cold is intense, in a latitude corresponding to that of central France, several tributaries of the St. Lawrence begin to thaw in their upper course, while they remain frozen over lower down, and thus large slabs of ice are set free and thrown upon the unbroken sheet of ice below. Then begins what is called the packing of the drifted fragments; that is to say, one slab is made to slide ever another, until a vast pile is built up, and the whole, being frozen together, is urged onwards by the force of the

* Consid. sur les Blocs errat. 1829.

BOULDERS DRIFTED BY ICE ON SHORES OF THE ST. LAWRENCE.

(View taken by Lieut. Bowen, from the N.E., in the Spring of 1835, at Richelieu Rapid, lat. 46 N.) See p. 365.

dammed-up waters and drift-ice. Thus propelled, it not only forces along boulders, but breaks off from cliffs, which border the rivers, huge pieces of projecting rock. By this means several buttresses of solid masonry, which, up to the year 1836, supported a wooden bridge on the St. Maurice, which falls into the St. Lawrence, near the town of Trois Rivières, lat 46° 20′, were thrown down, and conveyed by the ice into the main river; and instances have occurred at Montreal of wharfs and stone buildings, from 30 to 50 feet square, having been removed in a similar manner. We learn from Captain Bayfield that anchors laid down within high-water mark, to secure vessels hauled on shore for the winter, must be cut out of the ice on the approach of spring, or they would be carried away. In 1834, the Gulnare's bower-anchor, weighing half a ton, was transported some yards by the ice, and so firmly was it fixed, that the force of the moving ice broke a chain-cable suited for a 10-gun brig, and which had rode the Gulnare during the heaviest gales in the gulf. Had not this anchor been cut out of the ice, it would have been carried into deep water and lost.*

The scene represented in the annexed plate (Pl. IV.), from a drawing by Lieutenant Bowen, R.N., will enable the reader to comprehend the incessant changes which the transport of boulders produces annually on the low islands, shores, and bed of the St. Lawrence above Quebec. The fundamental rocks at Richelieu Rapid, situated in lat. 46° N., are limestone and slate, which are seen at low water to be covered with boulders of granite. These boulders owe their spheroidal form chiefly to weathering, or the action of frost, which causes the surface to exfoliate in concentric plates, so that all the more prominent angles are removed. At the point *a* is a cavity in the mud or sand of the beach, now filled with water, which was occupied during the preceding winter (1835) by the huge erratic *b*, a mass of granite, 70 tons' weight, found in the spring following (1836) at the distance of several feet from its former position. Many small islands are seen on the river, such as *c d*, which afford still more striking proofs of the carrying and propelling power of ice. These

* Capt. Bayfield, Geol. Soc. Proceedings, vol. ii. p. 223.

islets are never under water, yet every winter ice is thrown upon them in such abundance, that it *packs* to the height of 20, and even 30 feet, bringing with it a continual supply of large stones or boulders, and carrying away others; the greatest number being deposited, according to Lieutenant Bowen, on the edge of deep water. On the island *d*, on the left of the accompanying view, a lighthouse is represented, consisting of a square wooden building, which, having no other foundation than the boulders, requires to be taken down every winter, and rebuilt on the re-opening of the river.

These effects of frost, which are so striking on the St. Lawrence above Quebec, are by no means displayed on a smaller scale below that city, where the gulf rises and falls with the tide. On the contrary, it is in the estuary, between the latitudes 47° and 49°, that the greatest quantity of gravel and boulders of large dimensions are carried down annually towards the sea. Here the frost is so intense, that a dense sheet of ice is formed at low water, which, on the rise of the tide, is lifted up, broken, and thrown in heaps on the extensive shoals which border the estuary. When the tide recedes, this packed ice is exposed to a temperature sometimes 30° below zero, which freezes together all the loose pieces of ice, as well as the granitic and other boulders. The whole of these are often swept away by a high tide, or when the river is swollen by the melting of the snow in spring. One huge block of granite, 15 feet long by 10 feet both in width and height, and estimated to contain 1,500 cubic feet, was conveyed in this manner some distance in the year 1837, its previous position being well known, as up to that time it had been used by Captain Bayfield as a mark for the surveying station.

Ground-ice.—When a current of cold air passes over the surface of a lake or stream it abstracts from it a quantity of heat, and the specific gravity of the water being thereby increased, the cooled portion sinks. This circulation may continue until the whole body of fluid has been reduced to the temperature of 40° F., after which if the cold increase, the vertical movement ceases, the water which is uppermost expands and floats over the heavier fluid below, and when it

has attained a temperature of 32° Fahr. it sets into a sheet of ice. It would seem therefore impossible, according to this law of congelation, that ice should ever form at the bottom of a river; and yet such is the fact, and many speculations have been hazarded to account for so singular a phenomenon. M. Arago is of opinion that the mechanical action of a running stream produces a circulation by which the entire body of water is mixed up together and cooled alike, and the whole being thus reduced to the freezing point, ice begins to form at the bottom for two reasons, first, because there is less motion there, and secondly, because the water is in contact with solid rock or pebbles which have a cold surface.* Even in the Thames we learn from Dr. Plott that pieces of this kind of ice, having gravel frozen on to their under side, rise up from the bottom in winter, and float on the surface. In the Siberian rivers, Weitz describes large stones as having been brought up from the river's bed in the same manner, and made to float.† It is a common remark in Russia that where the bottom of the stream is muddy, ground-ice forms less readily, and that it is produced most freely when the sky is cloudless. In that case, stones lying in the channel part with their heat by radiation more rapidly. By an admirable provision of nature, it is in those countries where river-courses are most liable to be choked up by large stones brought down from the upper country by floating ice, that ground-ice comes to the aid of the carrying power of running water.

Glaciers.—As the atmosphere becomes colder in proportion as we ascend in it, there are mountainous heights even in tropical countries where the heat of summer is insufficient to melt the winter's snow. But to reach the lower limit of perpetual snow at the equator, we must rise to an elevation of about 16,000 feet above the sea (see above, p. 251). In the Swiss Alps, in lat. 46° N., we find the line of perpetual snow descending as low as 8,500 feet above the sea, the loftier peaks of the Alpine chain being from 12,000 to 15,000

* M. Arago, Annuaire, &c. 1833; and Rev. J. Farquharson, Phil. Trans. 1835, p. 329.

† Journ. of Roy. Geograph. Soc. vol. vi. p. 416.

feet high. The frozen mass augmenting from year to year would add indefinitely to the altitude of alpine summits, were it not relieved by its descent through the larger and deeper valleys to regions far below the general snow-line. To these it slowly finds its way in the form of rivers of ice called glaciers, the consolidation of which is produced by pressure, and by the congelation of water infiltered into the porous mass, which is always undergoing partial liquefaction

Fig. 28.

Glacier with medial and lateral moraines and with terminal cave.

on its surface. In a day of hot sunshine, or mild rain, innumerable rills of pure and sparkling water run in icy channels along the surface of the glaciers, which in the night shrink and come to nothing. They are often precipitated in bold cascades into deep fissures in the ice, and contribute together with springs to form torrents, which flow in tunnels at the bottom of the glaciers for many a league, and at

length issue at their extremities, from beneath beautiful caverns or arches. The waters of these streams are always densely charged with the finest mud, produced by the grinding of rock and sand under the weight of the moving mass. (See fig. 28.) The length of time during which these glaciers have existed must have been so great, and there is so much evidence of their dimensions having been formerly greater than now, that a considerable portion of the erosion, or of the widening and deepening of the valley must be attributed to ice-action. But to what extent the valleys in which the Swiss glaciers move were excavated by rivers before the valleys were filled with ice we have no positive data at present for deciding.

The length of the Swiss glaciers is sometimes between twenty and thirty miles; their width in the middle portion where they are broadest, occasionally two or three miles; their depth or thickness sometimes more than 600 feet. When they descend steep slopes and precipices, or are forced through narrow gorges, the ice is broken up, and assumes the most fantastic and picturesque forms, with lofty peaks and pinnacles, projecting above the general level. These snow-white masses are often relieved by a dark background of pines, as in the valley of Chamouni; and are not only surrounded with abundance of the wild rhododendron in full flower, but encroach still lower into the region of cultivation, and trespass on fields where the tobacco-plant is flourishing by the side of the peasant's hut.

The cause of glacier motion has during the last quarter of a century been a subject of careful investigation and much keen controversy. Although a question of physics, rather than of geology, it is too interesting to allow me to pass it by without some brief mention. De Saussure, whose 'Travels in the Alps' are full of original observations, as well as sound and comprehensive general views, conceived that the weight of the ice might be sufficient to urge it down the slope of the valley, if the sliding motion were aided by the water flowing at the bottom. For this 'gravitation theory' Charpentier, followed by Agassiz, substituted the hypothesis of dilatation. The most solid ice is always permeable to

water, and penetrated by innumerable fissures and capillary tubes, often extremely minute. These tubes imbibe the aqueous fluid during the day, which freezes, it is said, in the cold of the night, and expands while in the act of congelation. The distension of the whole mass exerts an immense force, tending to propel the glacier in the direction of least resistance—'in other words, down the valley.' This theory was opposed by Mr. Hopkins on mathematical and mechanical grounds, in several able papers. Among other objections, he pointed out that the friction of so enormous a body as a glacier on its bed is so great, that the vertical direction would always be that of least resistance, and if a considerable distension of the mass should take place, by the action of freezing, it would tend to increase its thickness, rather than accelerate its downward progress. He also contended (and his arguments were illustrated by many ingenious experiments) that a glacier can move along an extremely slight slope, solely by the influence of gravitation, owing to the constant dissolution of ice in contact with the rocky bottom, and the number of separate fragments into which the glacier is divided by fissures, so that freedom of motion is imparted to its several parts somewhat resembling that of an imperfect fluid. To this view Principal James D. Forbes objected that gravitation would not supply an adequate cause for the sliding of solid ice down slopes having an inclination of no more than four or five degrees, still less would it explain how the glacier advances where the channel expands and contracts. The Mer de Glace in Chamouni, for example, after being 2,000 yards wide, passes through a strait only 900 yards in width. Such a gorge, it is contended, would be choked up by the advance of any solid mass, even if it be broken up into numerous fragments. The same acute observer remarked, that water in the fissures and pores of glaciers cannot, and does not, part with its latent heat, so as to freeze every night to a great depth, or far in the interior of the mass. Had the dilatation theory been true, the chief motion of the glacier would have occurred about sunset, when the freezing of the water must be greatest, and it had, in fact, been at first assumed by those who favoured that hypothesis,

that the mass moved faster at the sides, where the melting of ice was promoted by the sun's heat, reflected from boundary precipices.

Agassiz appears to have been the first to commence, in 1841, aided by a skilful engineer, M. Escher von der Linth, a series of exact measurements to ascertain the laws of glacier motion, and he soon discovered, contrary to his preconceived notions, that the stream of ice moved more slowly at the sides than at the centre, and faster in the middle region of the glacier than at its extremity.* Principal J. D. Forbes, who had joined Professor Agassiz during his earlier investigations in the Alps, undertook himself an independent series of experiments, which he followed up with great perseverance, to determine the laws of glacier motion. These he found to agree very closely with the laws governing the course of rivers, their progress being greater in the centre than at the sides, and more rapid at the surface than at the bottom. This fact was verified by carefully fixing a great number of marks in the ice, arranged in a straight line, which gradually assumed a beautiful curve, the middle part pointing down the glacier, and showing a velocity there, double or treble that of the lateral parts.† He ascertained that the rate of advance by night was nearly the same as by day, and that even the hourly march of the icy stream could be detected, although the progress might not amount to more than six or seven inches in twelve hours. By the incessant though invisible advance of the marks placed on the ice, 'time,' says Mr. Forbes, 'was marked out as by a shadow on a dial, and the unequivocal evidence which I obtained, that even whilst walking on a glacier we are, day by day, and hour by hour, imperceptibly carried on by the resistless flow of the icy stream, filled me with admiration.'‡ In order to explain this remarkable regularity of motion, and its obedience to laws so strictly analogous to those of fluids, the same writer proposed the theory, the germ of which was first hinted by Rendu, that the ice, instead of being solid and

* See Système glaciaire, by Agassiz, Guyot, and Desor, pp. 436, 437, 445.

† J. D. Forbes. 8th Letter on Glaciers, Aug. 1844.

‡ J. D. Forbes. Travels in the Alps, 1st ed. p. 133.

compact, is a viscous or plastic body, capable of yielding to great pressure, and the more so in proportion as its temperature is higher, or as it approaches more nearly to the melting point. He endeavoured to show that this hypothesis would account for many complicated phenomena, especially for a ribboned or veined structure which is everywhere observable in the ice, and might be produced by lines of discontinuity, arising from the different rates at which the various portions of the semi-rigid glacier advance and pass each other. Many examples were adduced to prove that a glacier can model itself to the form of the ground over which it is forced, exactly as would happen if it possessed a certain ductility, and this power of yielding under intense pressure was supposed not to be irreconcilable with the idea of the ice being sufficiently compact to break into fragments when the strain upon its parts is excessive; as where the glacier turns a sharp angle, or descends upon a rapid or convex slope. The increased velocity in summer was attributed partly to the greater plasticity of the ice, when not exposed to intense cold, and partly to the hydrostatic pressure of the water in the capillary tubes, which imbibe more of this liquid in the hot season.

Mr. Hopkins, on the other hand, assuming the ice to be a rigid, not a viscous mass, attributed the more rapid motions in the centre to the unequal rate at which the broad stripes of ice, intervening between longitudinal fissures, advance; but besides that there are parts of the glacier where no such fissures exist, such a mode of progression, said Mr. Forbes, would cause the borders of large transverse rents, or 'crevasses,' to be jagged like a saw, instead of being perfectly even and straight-edged.* An experiment made in 1853 by Mr. Christie, secretary to the Royal Society, demonstrated that ice, under great pressure, possesses a sufficient degree of moulding and self-adapting power to allow it to be acted upon, as if it were a pasty or viscous substance. A hollow

* See Mr. Hopkins on Motion of Glaciers, Cambridge Phil. Trans. 1844, and Phil. Mag. 1845. Some of the concessions of this author as to a certain plasticity in the mass, made the difference between him and Principal Forbes little more than one of degree. (For the summary of Principal J. D. Forbes' views, see Phil. Trans. 1846, pt. 2.)

shell of iron an inch and a half thick, the interior being ten inches in diameter, was filled with water, in the course of a severe winter, and exposed to the frost, with the fuze-hole uppermost. A portion of the water expanded in freezing, so as to protrude a cylinder of ice from the fuze-hole; and this cylinder continued to grow inch by inch in proportion as the central nucleus of water froze. As we cannot doubt that an outer shell of ice is first formed, and then another within, the continued rise of the column through the fuze-hole must proceed from the squeezing of successive shells of ice, concentrically formed, through the narrow orifice; and yet the protruded cylinder consisted of entire, and not of fragmentary ice.*

When the hypothesis of viscosity had been so admirably worked out and illustrated by Forbes as to appear to be firmly established, Dr. Tyndall objected that it would account for a part only of the facts. Ice, he admitted, deports itself as a viscous body in cases where it is subjected to pressure alone, but when tension comes into play the analogy with a viscous body ceases. 'The glacier widens, bends, and narrows, and its centre moves more quickly than its sides. A viscous mass would undoubtedly do the same. But the most delicate experiments on the capacity of ice to yield to strain,—to stretch out like treacle, honey, or tar,—have failed to detect this stretching power. Is there,' he asks, 'then, any other physical quality to which the power of accommodation possessed by glacier-ice may be referred?'†

Faraday had called attention, in 1850, to the fact that if two pieces of ice having throughout a temperature of 32° F., and each melting at its surface, are made to touch each other, they will freeze together at the points of contact. This effect will take place even if the two pieces are plunged into hot water and held together for half a minute. In virtue of this property, which has been called 'regelation,' a mass of ice crushed into fragments may be squeezed forcibly into a mould, and then subjected to hydraulic pressure so that the parts are brought into still closer proximity. It is

* This experiment is cited by Mr. Forbes, Phil. Trans. 1846, p. 206.

† Tyndall, Heat as a Mode of Motion, 1863, pp. 185, 189.

then converted into a coherent cake of ice. All the touching surfaces of the icy fragments are cemented together by regelation, by virtue of which property the substance may be made to take any shape we please. 'It is easy, therefore,' says Tyndall, 'to understand how a substance so endowed can be squeezed through the gorges of the Alps—can bend so as to accommodate itself to the flexures of the Alpine valleys, and can permit of a differential motion of its parts, without at the same time possessing a sensible trace of viscosity.'

The agency of glaciers in producing permanent geological changes consists partly in their power of transporting gravel, sand, and huge stones to great distances, and partly in the smoothing, polishing, and scoring of their rocky channels, and the boundary walls of the valleys through which they pass. At the foot of every steep cliff or precipice in high Alpine regions, a talus is seen of rocky fragments detached by the alternate action of frost and thaw. If these loose masses, instead of accumulating on a stationary base, happen to fall upon a glacier, they will move along with it, and, in place of a single heap, they will form in the course of years a long stream of blocks. If a glacier be twenty miles long, and its annual progression about 500 feet, it will require about two centuries for a block thus lodged upon its surface to travel down from the higher to the lower regions, or to the extremity of the icy mass. This terminal point remains usually unchanged from year to year, although every part of the ice is in motion, because the liquefaction by heat is just sufficient to balance the onward movement of the glacier, which may be compared to an endless file of soldiers, pouring into a breach, and shot down as fast as they advance.

The stones carried along on the ice are called in Switzerland the 'moraines' of the glacier. There is always one line of blocks on each side or edge of the icy stream, and often several in the middle, where they are arranged in long ridges on mounds of snow and ice, often several yards high. The reason of their projecting above the general level is the non-liquefaction of the ice in those parts of the surface of the glacier which are protected from the rays of the sun, or the

action of the wind, by the covering of earth, sand, and stones. (See fig. 28, p. 364.) The cause of 'medial moraines' was first explained by Agassiz, who referred them to the confluence of tributary glaciers.* Upon the union of two streams of ice, the right lateral moraine of one of the streams comes in contact with the left lateral moraine of the other, and they afterwards move on together, in the centre, if the confluent glaciers are equal in size, or nearer to one side if unequal.

Fragments of stone and sand, which fall through crevasses in the ice and get interposed between the moving glacier and the fundamental rock, are pushed along so as to have their angles more or less worn off, and many of them are entirely ground down into mud. Some blocks are pushed along between the ice and the steep boundary rocks of the valley, and these, like the rocky channel at the bottom of the valley, often become smoothed and polished, and scored with parallel furrows, or with lines and scratches produced by hard minerals such as crystals of quartz, which act like the diamond upon glass.† This effect is perfectly different from that caused by the action of water, or a muddy torrent forcing along heavy stones; for these not being held fast like fragments of rock in ice, and not being pushed along under great pressure, cannot scoop out long rectilinear furrows or grooves parallel to each other.‡ The discovery of such markings at various heights far above the surface of the existing glaciers, and for miles beyond their present terminations, affords geological evidence of the former extension of the ice beyond its present limits in Switzerland and other countries.

The moraine of the glacier, observes Charpentier, is entirely devoid of stratification, for there has been no sorting of the materials, as in the case of sand, mud, and pebbles, when deposited by running water. The ice transports indifferently, and to the same spots, the heaviest blocks and the finest particles, mingling all together, and leaving them in one confused and promiscuous heap wherever it melts.§

* Études sur les Glaciers, 1840.

† See Elements of Geol. ch. xi.

‡ Agassiz, Jam. Ed. New Phil. Journ. No. 54, p. 388.

§ Charpentier, Ann. des Mines, tom. viii.; see also Papers by MM. Venetz and Agassiz.

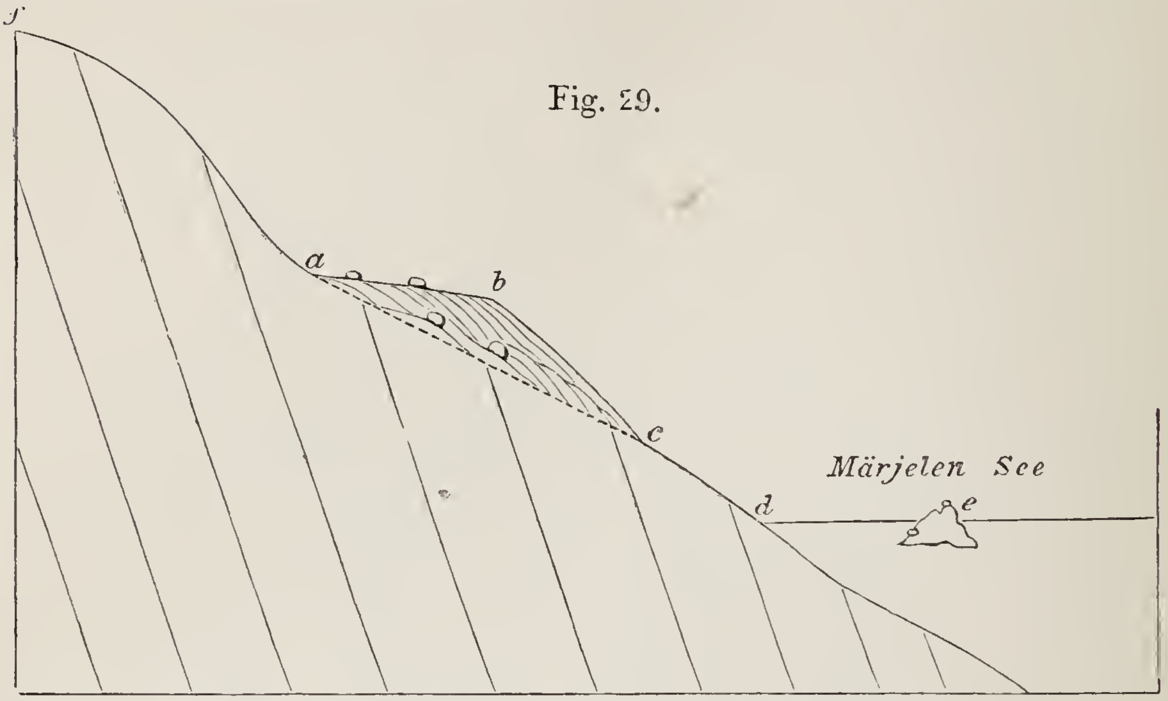
In the foreground of the woodcut, fig. 28, p. 364, some dome-shaped masses of smoothed rock are represented, called in Switzerland 'roches moutonnées,' for they are compared to the backs of sheep which are lying down. These owe their rounded and smooth outline to the action of the glacier when it was more in advance, the inequalities of the hard rock having been planed and rubbed off, in the manner before described. In 1857 I was able to pass for some distance under the terminal arch of the great glacier of the Viesch, a tributary of the Upper Rhone. It was in autumn (Sept. 1st), and during the preceding summer the glacier had retreated many yards. Under the arch on one side was a floor of white granite streaked, not only with straight furrows freshly made, but also with many parallel black lines which had been ruled by fragments of soft, dark blue slate, fixed in the moving ice. According as the impinging stones had been harder or softer than the floor over which they grated they had either cut lasting rectilinear furrows in the rock or had merely left superficial black markings which the glacier torrent of the ensuing winter would speedily wash away.

Glacier lake—Märjelen See.—There are several instances in the Himalaya where glaciers descending from lateral valleys cross the main valley and convert a portion of it into a lake by damming up the river. The converse of this may sometimes happen, as where a glacier descending the main valley causes a lake by blocking up the lower end of a tributary valley. An example of this occurs in the Swiss Alps, a few miles above Brieg, in the Canton of Valais, where the great glacier of Aletsch gives rise in this way to a small lake called the Märjelen See, which, after lasting for periods varying from three to five years, is periodically drained by changes which take place in the internal structure of the glacier. Rents or 'crevasses' in the ice open and give passage to the waters, which escape in a few hours, producing destructive inundations in the country below. Nothing is then left but a small stream flowing at the bottom of the basin, which last, after an interval of about a year, is again filled, the water rising to its old level, and

so continuing for several years. This old level is determined, not by the height of the glacier-dam, but by that of a watershed, or col, which separates the Märjelen See from the adjoining valley of the Viesch glacier, which lies to the eastward. (See fig. 30, p. 374.) The Märjelen See was about two miles in circumference when I visited it in August 1865, and about forty feet below its normal level; for in the month of June, in the preceding year, it had undergone one of its periodical drainages, and the basin had not yet been filled again. Such a state of things gave me an opportunity of examining a point of great geological interest, namely, the form and structure of a large terrace or line of beach which encircles the lake basin all round its margin, and which constitutes its shore when it is full, and when its surplus waters flow over to the Viesch valley. I satisfied myself that this terrace is a counterpart of one of those ancient shelves or parallel roads, as they are called, of Glen Roy in Scotland, which, as Agassiz first suggested, were probably formed on the edge of lakes dammed up by ice, which may have existed in the Glacial period in Scotland. The terrace or beach of the Märjelen See consists chiefly of sand and small pebbles of quartz, with stones of mica-schist, gneiss, granite, and a hornblende rock, most of them angular and from a few inches to four feet in diameter. The sand was stratified, but I could find no organic remains in it. The width of the shelf, *a b* (see fig. 29), is about sixteen paces, and its slope varies from angles of 5° to 15°. The slope from *b* to *c*, which is under water when the lake is full, has an angle of 29°. The vertical height of the upper part of the shelf *a*, above the lowest portion, *c*, is thirty-six feet. The fundamental rock consists of highly inclined mica-schist. The materials of the terrace or shelf are such as might have been derived chiefly from the waste of the steeply sloping flanks of the boundary heights *f a*, but they consist, no doubt, in part of fragments of rock, stranded by miniature icebergs, such as *e* (fig. 29), of which many are continually detached from the barrier of ice at the lower end of the lake. I saw many of these bergs floating on the lake, with stones and mud frozen into them, parts of the moraine

of the Aletsch Glacier, and which may have come from distant mountains. The icy fragments were melting, and

Fig. 29.

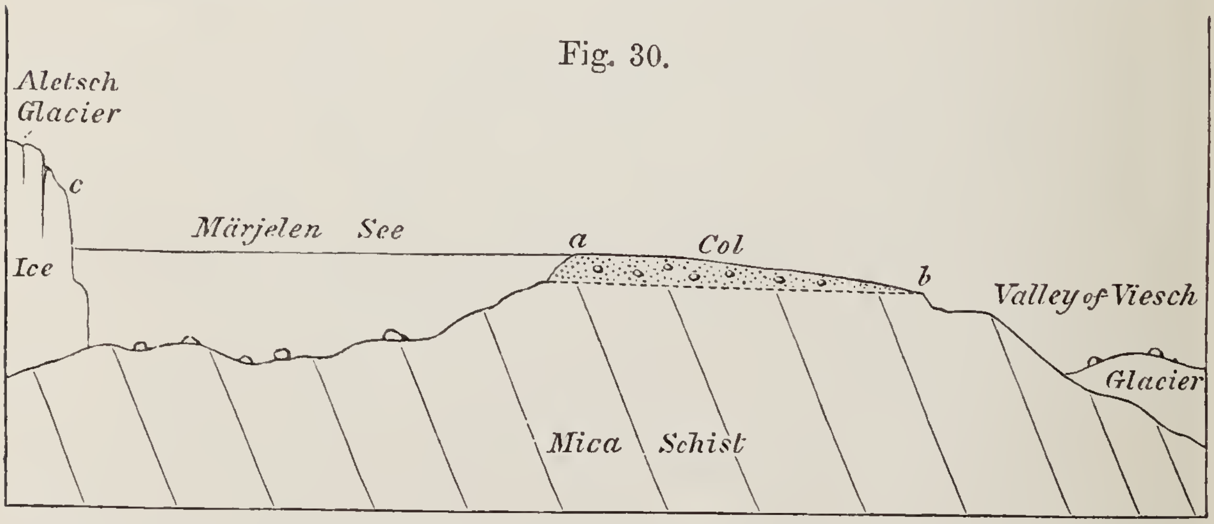


Section of the glacier lake called the Märjelen See.

a b c. Terrace of detrital matter formed on the margin of the lake when full.
d. Surface of lake 40 feet below its usual level.
e. Mass of floating ice with included stones detached from the dam.
f. Boundary hill composed of mica-schist.

as their centres of gravity changed, they frequently capsized. The materials thus transported must be strewed in part over the whole bottom of the lake, but by far the greater number

Fig. 30.



Relative position of the lake called Märjelen See and the Valley of Viesch.

a b. Col or dividing ridge between the two valleys.
c. Vertical cliff of ice forming the dam.

must be stranded on the shore when the lake is full, or in its normal condition. In fig. 30 the position of the lake

dammed up by the Aletsch Glacier, and its relation to the adjoining valley of Viesch are shown. The col or lowest depression between the two valleys is seen at *a b*, and along this level the stream issuing from the Märjelen See, at *a*, flows habitually to *b*, where it falls in a cascade over the rocks, on its way to the valley of Viesch. In passing from *a* to *b*, it cuts through ancient moraine matter, and its channel has been deepened artificially several feet, with a view of preventing the Märjelen See from rising to its full height, thereby lessening the magnitude of the floods caused by the bursting of the icy dam. The Mayor or Castellan of Viesch showed me an old document, from which I learnt that towards the end of the 17th century (1683) the government of the Canton of Valais were busy with a scheme for draining the Märjelen See, and diminishing the volume of its periodical inundations. This record is valuable, as teaching us that both the ordinary and exceptional condition of the lake, about two centuries ago, were the same as now.

Those geologists who have contended that the old beaches or parallel roads of Lochaber in Scotland were formed on the margins of sheets of water blocked up by ice, have sometimes been met with the objection that we can hardly imagine such a blockage to be permanent, or to retain the water steadily at the same level. Now, as to the constancy of the level, it is admitted that each of the Scotch shelves coincides with a watershed or col dividing the glen in which the shelf occurs from an adjoining glen. Provided the dam of ice be higher than this watershed, it may evidently vary in magnitude to any amount without in any way affecting the level of the beach or marginal terrace of detrital matter. But we also learn from the Märjelen See, that even if the ice-dam periodically gives way, and is renewed, after months or years, it will not, if the physical geography of the district remains unaltered, affect the constancy of the level at which the principal beach or road is formed.*

* In the 'Antiquity of Man' I have given a description of the 'parallel roads' alluded to, and have referred to the numerous authors on the subject, concluding with the papers of Mr. Jamieson, of Ellon, in support of the glacier-lake theory.

Icebergs.—In countries situate in high northern latitudes, like Spitzbergen, between 70° and 80° N., glaciers, loaded with mud and rock, descend to the sea, and there huge fragments of them float off and become icebergs. Scoresby counted 500 of these bergs drifting along in latitudes 69° and 70° N., which rose above the surface from the height of 100 to 200 feet, and measured from a few yards to a mile in circumference.* Many of them were loaded with beds of earth and rock of such thickness, that the weight was conjectured to be from 50,000 to 100,000 tons. Specimens of the rocks were obtained, and among them were granite, gneiss, mica-schist, clay-slate, granular felspar, and greenstone. Such bergs must be of great magnitude, because the mass of ice below the level of the water is about eight times greater than that above. Wherever they are dissolved, it is evident that the 'moraine' will fall to the bottom of the sea. In this manner many submarine valleys, mountains, and platforms become strewed over with gravel, sand, mud, and scattered blocks of foreign rock, of a nature perfectly dissimilar from all in the vicinity, and which may have been transported across unfathomable abysses. If the bergs happen to melt in still water, so that the earthy and stony materials may fall tranquilly to the bottom, the deposit will probably be unstratified, like the terminal moraine of a glacier; but whenever the materials are under the influence of a current of water as they fall, they will be sorted and arranged according to their relative weight and size, and therefore more or less perfectly stratified.

We have already stated that some ice-islands have been known to drift from Baffin's Bay to the latitude of the Azores, and from the South Pole to the immediate neighbourhood of the Cape of Good Hope, so that the area over which the effects of moving ice may be experienced comprehends a large portion of the globe.

In the account given by Messrs. Dease and Simpson, of their arctic discoveries in 1838, we learn that in lat. 71° N., long. 156° W., they found a long low spit, named Point Barrow, composed of gravel and coarse sand, in some parts

* Voyage in 1822, p. 233.

more than a quarter of a mile broad, which the pressure of the ice had forced up into numerous mounds, that, viewed from a distance, assumed the appearance of huge boulder rocks.'*

The fact is important, as showing how masses of drift-ice, when stranding on submarine banks, may exert a lateral pressure capable of bending and dislocating any yielding strata of gravel, sand, or mud. The banks on which icebergs occasionally run aground between Baffin's Bay and Newfoundland, are many hundred feet under water, and the force with which they are struck will depend not so much on the velocity as the momentum of the floating ice-islands. The same berg is often carried away by a change of wind, and then driven back again upon the same bank, or it is made to rise and fall by the waves of the ocean, so that it may alternately strike the bottom with its whole weight, and then be lifted up again, until it has deranged the superficial beds over a wide area. In this manner the geologist may account, perhaps, for the circumstance that in Scandinavia, Scotland, and other countries where erratics are met with, the beds of sand, loam, and gravel are often vertical, bent, and contorted into the most complicated folds, while the underlying strata, although composed of equally pliant materials, are horizontal. But some of these curvatures of loose strata may also have been due to repeated alternations of layers of gravel and sand, ice and snow, the melting of the latter having caused the intercalated beds of indestructible matter to assume their present anomalous position.

There can be little doubt that icebergs must often break off the peaks and projecting points of submarine mountains, and must grate upon and polish their surface, furrowing or scratching them, and reducing them to dome-shaped masses, in precisely the same way as we have seen that glaciers act on the solid rocks over which they are propelled.†

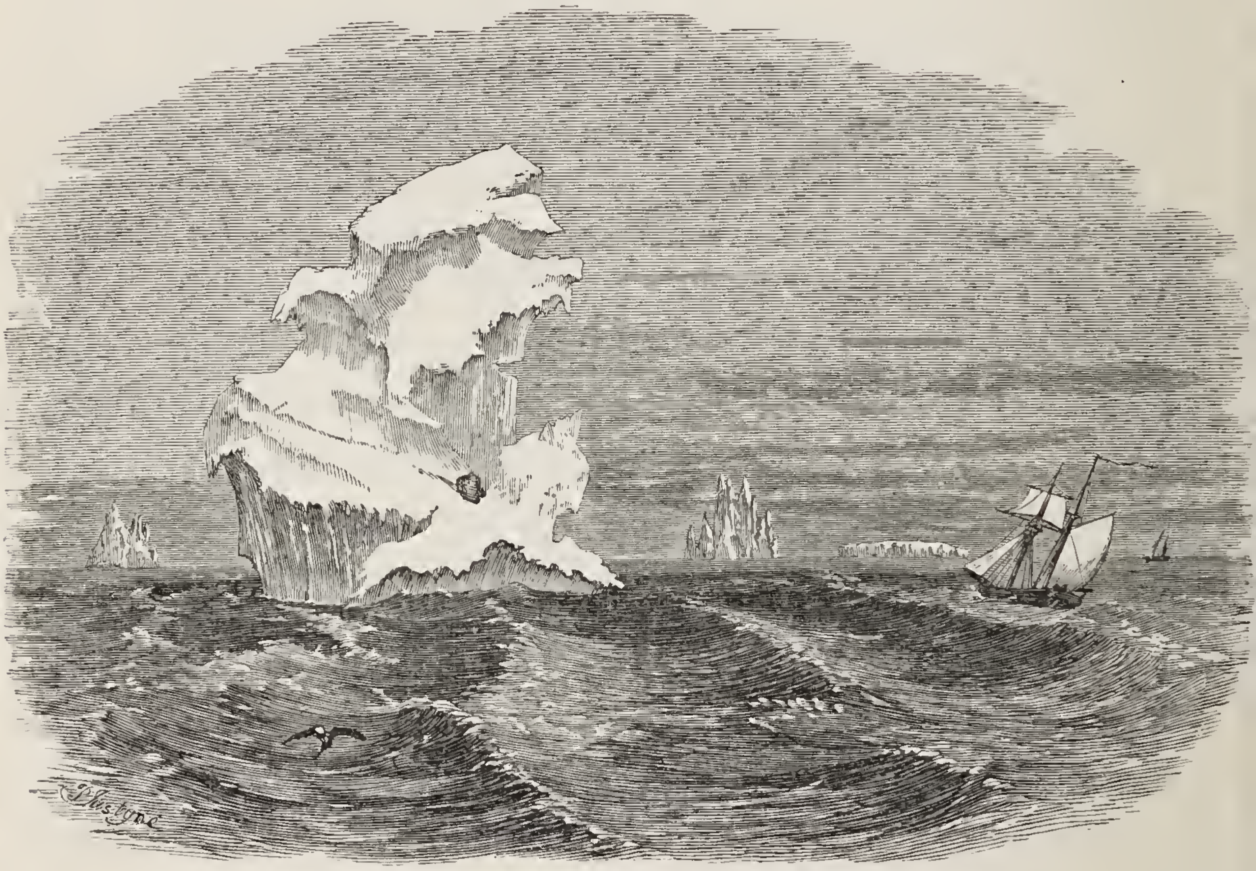
We learn from Von Buch that the most southern point on

* Journ. of Roy. Geograph. Soc. vol. viii. p. 221.

† In my Travels in N. America, pp. 19, 23, &c., and Second Visit to the U.S., vol. i. ch. 2, also in my Elements of Geology, 6th ed. p. 144, and Student's Elements, p. 150, a more full account of the action of floating ice and coast-ice, and its bearing on geology, will be found.

the continent of Europe at which a glacier comes down to the sea is in Norway, in lat. 67° N.* But Mr. Darwin has shown that they extend to the sea, in South America, in latitudes more than 20° nearer the equator than in Europe. Thus in Chili, for example, they occur, as before stated, in the Gulf of Penas, in the latitude of Central France; and in Sir George Eyre's Sound, in the latitude of Paris, they give origin to icebergs, which were seen in 1834 carrying angular pieces of granite, and stranding them in fiords, where the

Fig. 31.



Iceberg seen 1,400 miles E.N.E. of Enderby's Land.
Sketched by Mr. John M'Nab.†

shores were composed of clay-slate.‡ A certain proportion, however, of the ice-islands seen floating both in the northern and southern hemispheres, are probably not generated by glaciers, but rather by the accumulation of coast-ice. When the sea freezes at the base of a lofty precipice, the sheet of ice is prevented from adhering to the land by the rise and fall of the tide. Nevertheless, it often continues on shore at the

* Travels in Norway.

† Journ. of Roy. Geograph. Soc. vol. ix. p. 526.

‡ Darwin's Journal, p. 283.

foot of the cliff, and receives accessions of drift-snow blown from the land. Under the weight of this snow the ice sinks slowly if the water be deep, and the snow is generally converted into ice by partial liquefaction and re-congelation. In this manner, islands of ice, of great thickness and many leagues in length, originate, and are eventually blown out to sea by off-shore winds. In their interior are enclosed many fragments of stone which have fallen upon them from overhanging cliffs during their formation. Such floating icebergs are commonly flat-topped, but their lower portions are liable to melt in latitudes where the ocean at a moderate depth is usually warmer than the surface water and the air. Hence their centre of gravity changes continually, and they turn over and assume very irregular shapes.

In a voyage of discovery made in the antarctic regions in 1839, a dark-coloured angular mass of rock was seen imbedded in an iceberg, drifting along in mid ocean in lat. 61° S. That part of the rock which was visible was about 12 feet in height, and from 5 to 6 in width, but the dark colour of the surrounding ice indicated that much more of the stone was concealed. The annexed drawing (fig. 31) was made by Mr. M'Nab, when the vessel was a quarter of a mile distant.* This iceberg, one of many observed at sea on the same day, was between 250 and 300 feet high, and was no less than 1,400 miles from any certainly known land. It is exceedingly improbable, says Mr. Darwin, in his notice of this phenomenon, that any land will hereafter be discovered within 100 miles of the spot, and it must be remembered that the erratic was still firmly fixed in ice, and may have sailed for many a league farther before it dropped to the bottom.†

Captain Sir James Ross, in his antarctic voyage, in 1841-2 and 3, saw multitudes of icebergs transporting stones and rocks of various sizes, with frozen mud, in high southern latitudes. His companion, Dr. J. Hooker, informs me that he came to the conclusion, that most of the southern icebergs have stones in them, although they are usually concealed from view by the quantity of snow which falls upon them.

* Journ. of Roy. Geograph. Soc. vol. ix. p. 526. † Ibid.

Retransportation of ancient glacial boulders.—The borders of the Canadian lakes, and the beds of the torrents and rivers, about 1,000 in number, which flow into those lakes, are strewn with boulders and erratic blocks which are either distinctly glaciated, or polished and striated in such a way as to imply that they belong to the ancient period of intense cold, when the country was covered with glaciers. Every year great numbers of these blocks are lifted up by ground-ice from the bottom (see p. 362) when the river is frozen over, and on the breaking up of the ice they are carried down by the river into the lake, and drifted for a hundred miles or more in all directions by the wind, and fall to the bottom, so that at some future period geologists not on their guard might refer the glaciation of these blocks to the present era instead of the remote period at which they acquired their superficial ice-markings.*

Coast-ice.—It appears, then, that large stones, mud, and gravel are carried down by the ice of rivers, estuaries, and glaciers, into the sea, where the tides and currents of the ocean, aided by the wind, may cause them to drift for hundreds of miles from the place of their origin. But we have not yet considered the transporting agency of coast-ice, which is often very active on the shores of the ocean far from the points where rivers enter.

The saline matter which sea-water holds in solution prevents its congelation except where the most intense cold prevails. But the drifting of the snow from the land often renders the surface-water brackish near the coast, so that a sheet of ice is readily formed there; and by this means a large quantity of gravel is frequently conveyed from place to place, and heavy boulders also, when the coast-ice is packed into dense masses. Both the large and small stones, thus conveyed, usually travel in one direction like shingle-beaches, and this was observed to take place on the coast of Labrador and Gulf of St. Lawrence, between the latitudes 50° and 60° N., by Captain Bayfield during his survey in 1839. The line of coast alluded to is strewed over for a distance of no less than 700 miles with ice-borne boulders, often six feet in

* Letter of Henry Landor, Canada, to C. Darwin, March 10, 1869.

diameter, which are for the most part on their way from north to south, or in the direction of the prevailing current. Some points on this coast have been observed to be occasionally deserted, and then again at another season thickly bestrewed with erratics.

The accompanying drawing (fig. 32), for which I am indebted to Lieut. Bowen, R.N., represents the ordinary appearance of the Labrador coast, between the latitudes of 50° and 60° N. Countless blocks, chiefly granitic, and of various sizes, are seen lying between high and low water mark. Captain Bayfield saw similar masses carried by ice

Fig. 32.

Boulders, chiefly of granite, stranded by ice on the coast of Labrador, between lat. 50° and 60° N. (Lieut. Bowen, R.N.)

through the Straits of Belle Isle, between Newfoundland and the American continent, which he conceives may have travelled in the course of years from Baffin's Bay, a distance which may be compared in our hemisphere to the drifting of erratics from Lapland and Iceland as far south as Germany, France, and England.

It may be asked, In what manner have these erratic blocks been originally detached? We may answer that some have fallen from precipitous cliffs, others have been lifted up from the bottom of the sea, adhering by their tops to the ice, while others have been brought down by rivers and glaciers.

The erratics of North America are sometimes angular, but most of them have acquired a spheroidal form, either by friction or decomposition. The granite of Canada, as before remarked (p. 361), has a tendency to exfoliation, and scales off in concentric coats when exposed to the spray of the sea during severe frosts. The range of the thermometer in that country usually exceeds, in the course of the year, 100°, and sometimes 120° F.; and to prevent the granite used in the buildings of Quebec from peeling off in winter, it is necessary to oil and paint the squared stones.

In parts of the Baltic, such as the Gulf of Bothnia, where the quantity of salt in the water amounts in general to one fourth only of that in the ocean, the entire surface freezes over in winter to the depth of 5 or 6 feet. Stones are thus frozen in, and afterwards lifted up about 3 feet perpendicularly on the melting of the snow in summer, and then carried by floating ice-islands to great distances. Professor Von Baer states, in a communication on this subject to the Academy of St. Petersburg, that a block of granite, weighing a million of pounds, was carried by ice during the winter of 1837–8 from Finland to the island of Hockland; and two other huge blocks were transported about the years 1806 and 1814 by packed ice on the south coast of Finland, according to the testimony of the pilots and inhabitants, one block having travelled about a quarter of a mile, and lying about 18 feet above the level of the sea.*

More recently Dr. Forchhammer has shown that in the Sound, the Great Belt, and other places near the entrance of the Baltic, ground-ice forms plentifully at the bottom, and then rises to the surface, charged with sand, gravel, stones, and seaweed. Sheets of ice, also, with included boulders, are driven up on the coast during storms, and 'packed' to a height of 50 feet. The Danish professor relates a striking fact to prove that large quantities of rocky fragments are annually carried by ice out of the Baltic. 'In the year 1807,' he says, 'at the time of the bombardment of the Danish fleet, an English sloop of war, riding at anchor in the roads at Copenhagen, blew up. In 1844, or thirty-seven years

* Jam. Ed. New Phil. Journ. No. xlviii. p. 439.

afterwards, one of our divers, known to be a trustworthy man, went down to save whatever might yet remain in the shipwrecked vessel. He found the space between decks entire, but covered with blocks from six to eight cubic feet in size, and some of them heaped one upon the other. He also affirmed, that all the sunk ships which he had visited in the Sound, were in like manner strewed over with blocks.'

Dr. Forchhammer also informs us, that during an intense frost in February 1844 the Sound was suddenly frozen over, and sheets of ice, driven by a storm, were heaped up at the bottom of the Bay of Täarbeijk, theatening to destroy a fishing-village on the shore. The whole was soon frozen together into one mass, and forced up on the beach, forming a mound more than 16 feet high, which threw down the walls of several buildings. 'When I visited the spot next day, I saw ridges of ice, sand, and pebbles, not only on the shore, but extending far out into the bottom of the sea, showing how greatly its bed had been changed, and how easily, where it is composed of rock, it may be furrowed and streaked by stones firmly fixed in the moving ice.'*

* Bulletin de la Soc. Géol. de France, 1847, tom. iv. pp. 1182, 1183.

CHAPTER XVII.

PHENOMENA OF SPRINGS.

ORIGIN OF SPRINGS—ARTESIAN WELLS—BORINGS AT PARIS—LIVE FISH RISING IN THE ARTESIAN WELLS IN THE SAHARA—DISTINCT CAUSES BY WHICH MINERAL AND THERMAL WATERS MAY BE RAISED TO THE SURFACE—THEIR CONNECTION WITH VOLCANIC AGENCY—THERMAL WATERS OF BATH—CALCAREOUS SPRINGS—TRAVERTIN OF THE ELSA—BATHS OF SAN VIGNONE AND OF SAN FILIPPO, NEAR RADICOFANI—SPHEROIDAL STRUCTURE IN TRAVERTIN—LAKE OF THE SOLFATARA, NEAR ROME—TRAVERTIN AT CASCADE OF TIVOLI—GYPSEOUS, SILICEOUS, AND FERRUGINOUS SPRINGS—BRINE SPRINGS—CARBONATED SPRINGS—DISINTEGRATION OF GRANITE IN AUVERGNE—PETROLEUM SPRINGS—PITCH LAKE OF TRINIDAD.

Origin of springs.—The action of running water on the surface of the land having been considered, we may next turn our attention to what may be termed 'the subterranean drainage,' or the phenomena of springs. Everyone is familiar with the fact, that certain porous soils, such as loose sand and gravel, absorb water with rapidity, and that the ground composed of them soon dries up after heavy showers. If a well be sunk in such soils, we often penetrate to considerable depths before we meet with water; but this is usually found on our approaching some lower part of the porous formation where it rests on an impervious bed; for here the water, unable to make its way downwards in a direct line, accumulates as in a reservoir, and is ready to ooze out into any opening which may be made, in the same manner as we see the salt water filtrate into, and fill, any hollow which we dig in the sands of the shore at low tide.

The facility with which water can percolate loose and gravelly soils is clearly illustrated by the effect of the tides in the Thames between Richmond and London. The river, in this part of its course, flows through a bed of gravel overlying clay, and the porous superstratum is alternately saturated by the water of the Thames as the tide rises, and

then drained again to the distance of several hundred feet from the banks when the tide falls, so that the wells in this tract regularly ebb and flow.

The transmission of water through a porous medium being so rapid, we may easily understand why springs are thrown out on the side of a hill, where the upper set of strata consist of chalk, sand, or other permeable substances, while the subjacent are composed of clay or other retentive soils. The only difficulty, indeed, is to explain why the water does not ooze out everywhere along the line of junction of the two formations, so as to form one continuous land-soak, instead of a few springs only, and these oftentimes far distant from each other. The principal cause of such a concentration of the waters at a few points is, first, the existence of inequalities in the upper surface of the impermeable stratum, which lead the water, as valleys do on the external surface of a country, into certain low levels and channels; and, secondly, the frequency of rents and fissures, which act as natural drains. That the generality of springs owe their supply to the atmosphere is evident from this, that they vary in the different seasons of the year, becoming languid or entirely ceasing to flow after long droughts, and being again replenished after a continuance of rain. Many of them are probably indebted for the constancy and uniformity of their volume to the great extent of the subterranean reservoirs with which they communicate, and the time required for these to empty themselves by percolation. Such a gradual and regulated discharge is exhibited, though in a less perfect degree, in all great lakes; for these are not sensibly affected in their levels by a sudden shower, but are only slightly raised, and their channels of efflux, instead of being swollen suddenly like the bed of a torrent, carry off the surplus water gradually.

Much light has been thrown, of late years, on the theory of springs, by the boring of what are called by the French 'Artesian wells,' because the method has long been known and practised in Artois: and it is now demonstrated that there are sheets, and in some places currents, of fresh water,

at various depths in the earth. The instrument employed in excavating these wells is a large auger, and the cavity bored is usually from three to four inches in diameter. If a hard rock is met with, it is first triturated by an iron rod, and the materials, being thus reduced to small fragments or powder, are readily extracted. To hinder the sides of the well from falling in, as also to prevent the spreading of the ascending water in the surrounding soil, a jointed pipe is introduced, formed of wood in Artois, but in other countries more commonly of metal. It frequently happens that, after passing through hundreds of feet of retentive soils, a water-bearing stratum is at length pierced, when the fluid immediately ascends to the surface and flows over. The first rush of the water up the tube is often violent, so that for a time the water plays like a fountain, and then, sinking, continues to flow over tranquilly, or sometimes remains stationary at a certain depth below the orifice of the well. This spouting of the water in the first instance is owing to the disengagement of air and carbonic acid gas, both of which often bubble up with the water.*

At Sheerness, at the mouth of the Thames, a well was bored on a low tongue of land near the sea, through 300 feet of the blue clay of London, below which a bed of sand and pebbles was entered, belonging, doubtless, to the Woolwich beds: when this stratum was pierced, the water burst up with impetuosity, and filled the well. By another perforation at the same place, the water was found at the depth of 328 feet below the surface clay; it first rose rapidly 189 feet, and then, in the course of a few hours, ascended to an elevation of 8 feet above the level of the ground. In 1824 a well was dug at Fulham, near the Thames, at the Bishop of London's, to the depth of 317 feet, which, after traversing the Tertiary strata, was continued through 67 feet of chalk. The water immediately rose to the surface, and the discharge was about 50 gallons per minute. In the garden of the Horticultural Society at Chiswick, the borings passed through 19 feet of gravel, 242½ feet of clay and loam, and 67½ feet of chalk, and

* Consult J. Prestwich, Water-bearing Strata around London. 1851. (Van Voorst.)

the water then rose to the surface from a depth of 329 feet.* At the Duke of Northumberland's, above Chiswick, the borings were carried through a still greater thickness of incumbent strata down to the chalk, which was reached at the depth of 620 feet, when a considerable volume of water was obtained, which rose 4 feet above the surface of the ground. In a well of Mr. Brooks, at Hammersmith, the rush of water from a depth of 360 feet was so great as to inundate several buildings and do considerable damage; and at Tooting, a sufficient stream was obtained to turn a wheel, and raise the water to the upper stories of the houses.† In 1838, the total supply obtained from the chalk near London was estimated at six million gallons a day, and in 1851 at nearly double that amount, the increase being accompanied by an average fall of no less than two feet a year in the level to which the water rose. The water stood commonly, in 1822, at high-water mark, and had sunk in 1851 to 45, and in some wells to 65, feet below high-water mark.‡ This fact shows the limited capacity of the subterranean reservoir.

In the last of three wells bored through the chalk at Tours, to the depth of several hundred feet, the water rose 32 feet above the level of the soil, and the discharge amounted to 300 cubic yards of water every twenty-four hours.§ By way of a scientific experiment, the sinking of a well was commenced at Grenelle, in the suburbs of Paris, in 1834, which had reached, in November 1839, a depth of more than 1,600 English feet, and yet no water ascended to the surface. The government were persuaded by M. Arago to persevere, if necessary, to the depth of more than 2,000 feet; but when they had descended above 1,800 English feet below the surface, and reached the chloritic series (or upper greensand), the water rushed up through the boring, which was about 10 inches in diameter at its upper, and 6 at its lower, extremity. The discharge every twenty-four hours was at the rate of half a million of gallons of limpid and warm water, the temperature being 82° F. This implies an

* Sabine, Journ. of Sci. No. xxxiii. p. 72, 1824.

† Héricart de Thury, 'Puits forés,' p. 49.

‡ Prestwich, p. 69.

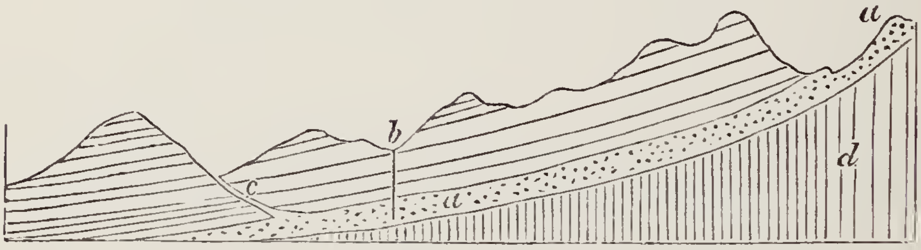
§ Bull. de la Soc. Géol. de France, tom. iii. p. 194.

augmentation of 30° F. beyond the average of springs in the latitude of Paris, making a rate of increase of 1° F. for every 60 English feet of descent. The depth at which the successive strata, both tertiary and cretaceous, were encountered, agreed very closely with the anticipations of the scientific advisers of this most spirited undertaking.

Mr. Briggs, the British consul in Egypt, obtained water between Cairo and Suez, in a calcareous sand, at the depth of 30 feet; but it did not rise in the well.* But other borings in the same desert, of variable depth, between 50 and 300 feet, and which passed through alternations of sand, clay, and siliceous rock, yielded water at the surface.†

The rise and overflow of the water in Artesian wells is generally referred, and apparently with reason, to the same principle as the play of an artificial fountain. Let the porous stratum or set of strata, *a a*, rest on the impermeable rock *d*,

Fig. 33.



and be covered by another mass of an impermeable nature. The whole mass *a a* may easily, in such a position, become saturated with water, which may descend from its higher and exposed parts—a hilly region where rain falls abundantly. Suppose that at some point, as at *b*, an opening be made, which gives a free passage upwards to the waters confined in *a a*, at so low a level, that they are subjected to the pressure of a considerable column of water collected in the more elevated portion of the same stratum. The water will then rush out, just as the liquid from a large barrel which is tapped, and it will rise to a height corresponding to the level of its point of departure, or, rather, to a height which balances the pressure previously exerted by

* Boué, Résumé des Prog. de la Géol. en 1832, p. 184.

† Seventh Rep. Brit. Assoc. 1837, p. 66.

the confined waters against the roof and sides of the stratum or reservoir *a a*. In like manner, if there happen to be a natural fissure *c*, a spring will be produced at the surface on precisely the same principle.

Among the causes of the failure of Artesian wells, we may mention those numerous rents and faults which abound in some rocks, and the deep ravines and valleys by which many countries are traversed; for, when these natural lines of drainage exist, there remains a small quantity only of water to escape by artificial issues. We are also liable to be baffled by the great thickness either of porous or impervious strata, or by the dip of the beds, which may carry off the waters from adjoining high lands to some trough in an opposite direction, as when the borings are made at the foot of an escarpment where the strata incline inwards, or in a direction opposite to the face of the cliffs.

The mere distance of hills or mountains need not discourage us from making trials: for the waters which fall on these higher lands readily penetrate to great depths through highly inclined or vertical strata, or through the fissures of shattered rocks, and, after flowing for a great distance, must often re-ascend and be brought up again by other fissures, so as to approach the surface in the lower country. Here they may be concealed beneath a covering of undisturbed horizontal beds, which it may be necessary to pierce in order to reach them. It should be remembered, that the course of waters flowing under ground bears but a remote resemblance to that of rivers on the surface, there being, in the one case, a constant descent from a higher to a lower level from the source of the stream to the sea; whereas, in the other, the water may at one time sink far below the level of the ocean, and afterwards rise again high above it.

Among other curious facts ascertained by aid of the borer, it is proved that, in strata of different ages and compositions, there are often open passages by which the subterranean waters circulate. Thus, at St. Ouen, in France, five distinct sheets of water were intersected in a well, and from each of these a supply obtained. In the third water-bearing stratum, at the depth of 150 feet, a cavity was found in which the

borer fell suddenly about a foot, and thence the water ascended in great volume.* A similar falling of the instrument several feet perpendicularly, as if in a hollow space, has been remarked in England and other countries. At Tours, in 1830, a well was perforated quite through the chalk, when the water suddenly brought up, from a depth of 364 feet, a great quantity of fine sand, with much vegetable matter and shells. Branches of a thorn several inches long, much blackened by their stay in the water, were recognised, as also the stems of marsh plants, and some of their roots, which were still white, together with the seeds of the same in a state of preservation, which showed that they had not remained more than three or four months in the water. Among the seeds were those of the marsh-plant *Galium uliginosum;* and among the shells, a fresh-water species, *Planorbis marginatus*, and some land species, as *Helix rotundata* and *H. striata*. M. Dujardin, who, with others, observed this phenomenon, supposes that the waters had flowed from some valleys of Auvergne or the Vivarais, distant about 150 miles, since the preceding autumn.†

An analogous phenomenon is recorded at Reimke, near Bochum in Westphalia, where the water of an Artesian well brought up, from a depth of 156 feet, several small fish, three or four inches long, the nearest streams in the country being at the distance of some leagues.‡ In some Artesian wells sunk by the French in the north-eastern part of the desert of the Sahara, small fish have been frequently brought up alive, with the first gush of water, from a depth of 175 feet. M. Désor informs us that in January 1863 he saw some of these fish in a well in the Oasis of Ain-Tala. They were of the genus Cyprinodon, not blind like those taken from the underground caverns of Adelsberg or Kentucky, but with perfect eyes.§ The nearest ponds or lakes were at a great distance on the surface of the desert, and in this and the other cases before mentioned of the subterranean transportation of shells, fish, and fragments of plants, we

* H. de Thury, p. 295.

† Bull. de la Soc. Géol. de France, tom. i. p. 93.

‡ Ibid. tom. ii. p. 248.

§ Gazette de Lausanne, Jan. 1864.

see evidence of the water not having been simply filtered through porous rock, but having flowed through continuous underground channels. Such examples suggest the idea that the leaky beds of rivers are often the feeders of springs.

MINERAL AND THERMAL SPRINGS.

Almost all springs, even those which we consider the purest, are impregnated with some foreign ingredients, which, being in a state of chemical solution, are so intimately blended with the water as not to affect its clearness, while they render it in general more agreeable to our taste, and more nutritious than simple rain-water. But the springs called mineral contain an unusual abundance of earthy matter in solution, and the substances with which they are impregnated correspond remarkably with those evolved in a gaseous form by volcanos. Many of these springs are thermal, or have a higher temperature than that which belongs to ordinary springs in the same neighbourhood, and they rise up through all kinds of rock; as, for example, through granite, gneiss, limestone, or lava, but are most frequent in volcanic regions, or where violent earthquakes have occurred at eras comparatively modern.

The water given out by hot springs is generally more voluminous and less variable in quantity at different seasons than that proceeding from any others. In many volcanic regions, jets of steam, called by the Italians 'stufas,' issue from fissures, at a temperature high above the boiling point, as in the neighbourhood of Naples, and in the Lipari Isles, and are disengaged unceasingly for ages. Now, if such columns of steam, which are often mixed with other gases, should be condensed before reaching the surface by coming in contact with strata filled with cold water, they may give rise to thermal and mineral springs of every degree of temperature. It is, indeed, by such means rather than by hydrostatic pressure that in many cases we can best account for the rise of large bodies of water from great depths; nor can we hesitate to admit the adequacy of the cause, if we suppose the expansion of the same elastic fluids to be sufficient to raise columns of lava to the lofty summits of volcanic mountains. Several gases, carbonic acid in particular, are disengaged in a free

state from the soil of various districts, especially in regions of active or extinct volcanos; and the same are found more or less intimately combined with the waters of all mineral springs, both cold and thermal. Dr. Daubeny and other writers have remarked, not only that these springs are most abundant in volcanic regions, but that, when remote from them, their site usually coincides with the position of some great derangement in the strata; a fault, for example, or great fissure, indicating that a channel of communication has been opened with the interior of the earth at some former period of local convulsion. It is also ascertained that at great heights in the Pyrenees and Himalaya Mountains, hot springs burst out from granitic rocks, and they are abundant in the Alps also, these chains having all been disturbed and dislocated at times comparatively modern, as can be shown by independent geological and sometimes historical evidence.

The small area of volcanic regions may appear, at first sight, to present an objection to these views, but not so when we include earthquakes among the effects of igneous agency. A large proportion of the land hitherto explored by geologists can be shown to have been rent or shaken by subterranean movements since the oldest Tertiary strata were formed. It will also be seen, in the sequel, that new springs have burst out, and others have had the volume of their waters augmented, and their temperature suddenly raised, after earthquakes, so that the description of these springs might almost with equal propriety have been given under the head of 'igneous causes,' as they are agents of a mixed nature, being at once igneous and aqueous.

As examples of changes which have occurred in historical times, I may here mention, that during the great earthquake at Lisbon in 1755, the temperature of the spring called La Source de la Reine, at Bagnères de Luchon in the Pyrenees, was suddenly raised as much as 75° F., or changed from a cold spring to one of 122° F., a heat which it has since retained. It is also recorded that the hot springs at Bagnères di Bigorre, in the same mountain-chain, became suddenly cold during a great earthquake which, in 1660, threw down several houses in that town.

But how, it will be asked, can the regions of volcanic heat send forth such inexhaustible supplies of water? The difficulty of solving this problem would, in truth, be insurmountable, if we believed that all the atmospheric waters found their way into the basin of the ocean; but, in boring near the shore, we often meet with streams of fresh water at the depth of several hundred feet below the sea level; and most of these probably descend far beneath the bottom of the sea. Yet, how much greater may be the quantity of salt water which sinks beneath the floor of the ocean, through the porous strata of which it is often composed, or through fissures rent in it by earthquakes! After penetrating to a considerable depth, this water may encounter a heat of sufficient intensity to convert it into vapour, even under the high pressure to which it would then be subjected. This heat would probably be nearest the surface in volcanic countries, and farthest from it in those districts which have been longest free from eruptions or earthquakes.

In corroboration of such an opinion, I may mention, that in regions where volcanic eruptions still occur, hot springs are abundant, and occasionally attain a boiling temperature, while, in proportion as we recede from such centres of igneous activity, the thermal waters decrease in frequency and average heat. In central France, or in the Eifel in Germany, we find cones and craters so perfect in their form, and streams of lava bearing such a relation to the shape of existing valleys, as to indicate that the internal fires have become dormant in comparatively recent times. It is precisely in these countries that hot springs play a conspicuous part.

It would follow, from the views above explained, that there must be a twofold circulation of terrestrial waters; one caused by solar heat, and the other by heat generated in the interior of our planet. We know that the land would be unfit for vegetation, if deprived of the waters raised into the atmosphere by the sun; but it is also true that mineral springs are powerful instruments in rendering the surface subservient to the support of animal and vegetable life. Their heat is believed to promote the development of the aquatic tribes in many parts of the ocean, and the substances which they carry

up from the bowels of the earth to the habitable surface, are of a nature and in a form which adapt them peculiarly for the nutrition of animals and plants.

As these springs derive their chief importance to the geologist from the quantity and quality of the earthy materials which, like volcanos, they convey from below upwards, they may properly be considered in reference to the ingredients which they hold in solution. These consist of a great variety of substances; but chiefly salts composed of carbonic, sulphuric, and hydrochloric acids combined with bases of lime, magnesia, alumina, and iron. Chloride of sodium, silica, and free carbonic acid, as well as nitrogen, are commonly present; there are also springs of petroleum or liquid bitumen, and of naphtha.

The ingredients of mineral springs, such as common salt, chloride of magnesium, and others, so often agree with the constituents of sea-water, that the theory of their marine origin has been naturally suggested. Such materials are, no doubt, often to be obtained from those strata through which the descending rain-water flows; but in many cases they may come from the sea even where the substances are not found in the same relative proportions as in sea-water; for, where hot springs charged with gaseous matter penetrate through rocky masses, the decomposition of various minerals must often be going on; and, where new chemical combinations take place, some of the gaseous, earthy, or metallic ingredients of springs may be intercepted in their upward course.

Among the gases, nitrogen is often largely evolved from springs, as it is from volcanic craters during eruptions. This gas may be derived, says Dr. Daubeny, from atmospheric air, which is always dissolved in rain-water, and which, when this water penetrates the earth's crust, must be carried down to great depths, so as to reach the heated interior. When there, it may be subjected to deoxidating processes, so that the nitrogen, being left in a free state, may be driven upwards by the expansive force of heat and steam, or by hydrostatic pressure.

Thermal waters of Bath.—The hot springs of Bath may

serve as an example of mineral waters containing in solution a variety of ingredients frequently met with in thermal springs. Their mean temperature is 120° Fahr., which is not only much above that of any other springs in England, but is exceptionally high in Europe, when we take into account their great distance from any region of active or extinct volcanos, or of violent earthquakes. Thus they are 400 miles distant from the Eifel volcanos, lying E.S.E. of them, and 440 miles from those (also extinct) of Auvergne, which lie to the S.E. The daily evolution of nitrogen gas amounts, according to Dr. Daubeny, to no less than 250 cubic feet in volume. This gas is largely disengaged from volcanic craters during eruptions, and carbonic acid gas is also evolved from the same springs. The other substances held in solution are the sulphates of lime and of soda, and the chlorides of sodium and magnesium. As the uniformity of temperature at all seasons of the year is remarkable in this, and in thermal springs generally, so is the uniformity of the discharge of water from century to century, and of the mineral ingredients held in solution. If we compare the hot water forced up by springs from below to the vast clouds of aqueous vapour evolved, for days or weeks in succession, from volcanic craters in eruption, so we may liken the voluminous masses of solid matter raised from great depths by the hot spring, to the lava which the volcano pours out on the surface. There is more analogy in the work done by the two agents, in raising up matter from great depths, than is commonly imagined. The waters of Bath are not conspicuous among European hot springs for the quantity of foreign matter which they contain, yet Professor Ramsay has calculated that, if the mineral ingredients which they pour out were solidified, they would form in one year a square column nine feet in diameter, and no less than 140 feet in height. All this matter is now quietly conveyed by a stream of limpid water, in an invisible form, to the Avon, and by the Avon to the sea; but if, instead of being thus removed, it were deposited round the orifice of eruption, like the siliceous layers which encrust the circular basin of an Icelandic geyser, we should soon see a considerable cone built up, with a crater in the

middle; and if the action of the spring were intermittent, so that ten or twenty years should elapse between the periods when solid matter was emitted, or (say) an interval of three centuries, as in the case of Vesuvius between 1306 and 1631, the discharge would be on so grand a scale as to afford no mean object of comparison with the intermittent outpourings of a volcano.*

Calcareous springs.—Springs which are highly charged with calcareous matter produce a variety of phenomena of much interest in geology. It is known that rain-water collecting carbonic acid from the atmosphere has the property of dissolving the calcareous rocks over which it flows, and thus, in the smallest ponds and rivulets, matter is often supplied for the earthy secretions of testacea, and for the growth of certain plants on which they feed. But many springs hold so much carbonic acid in solution, that they are enabled to dissolve a much larger quantity of calcareous matter than rain-water; and when the acid is dissipated in the atmosphere, the mineral ingredients are thrown down, in the form of porous tufa or of more compact travertin.

Auvergne.—Calcareous springs, although most abundant in limestone districts, are by no means confined to them, but flow out indiscriminately from all rock formations. In Central France, a district where the primary rocks are unusually destitute of limestone, springs copiously charged with carbonate of lime rise up through the granite and gneiss. Some of these are thermal, and probably derive their origin from the deep source of volcanic heat, once so active in that region. One of these springs, at the northern base of the hill upon which Clermont is built, issues from volcanic peperino, which rests on granite. It has formed, by its incrustations, an elevated mound of travertin or white concretionary limestone, 240 feet in length, and, at its termination, sixteen feet high and twelve wide. Another incrusting spring in the same department, situated at Chaluzet, near Pont Gibaud, rises in a gneiss country, at the foot of a regular volcanic cone, at least twenty miles from any calcareous rock.

* Lyell. Anniversary Address, British Association, 1864.

Some masses of tufaceous deposit, produced by this spring, have an oolitic texture.

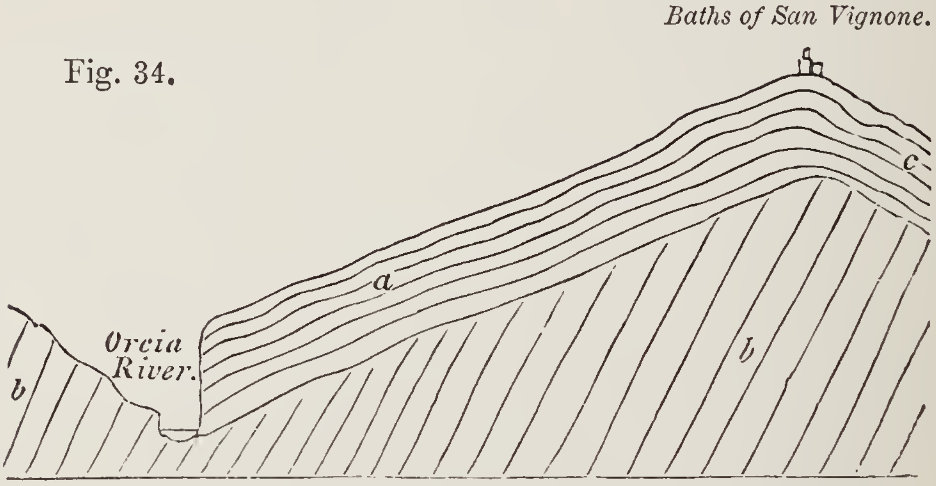
Valley of the Elsa.—If we pass from the volcanic district of France to that which skirts the Apennines in the Italian peninsula, we meet with innumerable springs which have precipitated so much calcareous matter that the whole ground in some parts of Tuscany is coated over with tufa and travertin, and sounds hollow beneath the foot.

In other places in the same country, compact rocks are seen descending the slanting sides of hills, very much in the manner of lava currents, except that they are of a white colour and terminate abruptly when they reach the course of a river. These consist of a calcareous precipitate from springs, some of which are still flowing, while others have disappeared or changed their position. Such masses are frequent on the slope of the hills which bound the valley of the Elsa, one of the tributaries of the Arno, which flows near Colle, through a valley several hundred feet deep, shaped out of a lacustrine formation, containing fossil shells of existing species. I observed here that the travertin was unconformable to the lacustrine beds, its inclination according with the slope of the sides of the valley. One of the finest examples which I saw was at the Molino delle Caldane, near Colle. The Sena and several other small rivulets which feed the Elsa have the property of incrusting wood and herbs with calcareous stone. In the bed of the Elsa itself, aquatic plants, such as Charæ, which absorb large quantities of carbonate of lime, are very abundant.

Baths of San Vignone.—Those persons who have merely seen the action of petrifying waters in England, will not easily form an adequate conception of the scale on which the same process is exhibited in those regions which lie nearer to the active centres of volcanic disturbance. One of the most striking examples of the rapid precipitation of carbonate of lime from thermal waters, occurs in the hill of San Vignone in Tuscany, at a short distance from Radicofani, and only a few hundred yards from the high road between Siena and Rome. The spring issues from near the summit of a rocky hill, about 100 feet in height. The top of the hill stretches

in a gently inclined platform to the foot of Mount Amiata, a lofty eminence, which consists in great part of volcanic products. The fundamental rock, from which the spring issues, is a black slate, with serpentine (*b b*, fig. 34), belonging to the older Apennine formation. The water is hot, has a strong taste, and, when not in very small quantity, is of a bright green colour. So rapid is the deposition near the source, that in the bottom of a conduit pipe for carrying off the water to the baths, and which is inclined at an angle of 30°, half a foot of solid travertin is formed every year. A more compact rock is produced where the water flows slowly; and the precipitation in winter, when there is least evaporation, is said to be more solid, but less in quantity by one fourth, than in summer. The rock is generally white; some

Fig. 34.



Section of travertin, San Vignone.

parts of it are compact, and ring to the hammer; others are cellular, and with such cavities as are seen in the carious part of bone or the siliceous millstone of the Paris basin. A portion of it also below the village of San Vignone consists of incrustations of long vegetable tubes, and may be called tufa. Sometimes the travertin assumes precisely the botryoidal and mammillary forms, common to similar deposits in Auvergne, of a much older date; and, like them, it often scales off in thin, slightly undulating layers.

A large mass of travertin (*c*, fig. 34) descends the hill from the point where the spring issues, and reaches to the distance of about half a mile east of San Vignone. The beds take the slope of the hill at about an angle of 6°, and the planes of stratification are perfectly parallel. One stratum, com-

posed of many layers, is of a compact nature, and fifteen feet thick; it serves as an excellent building stone, and a mass of fifteen feet in length was, in 1828, cut out for the new bridge over the Orcia. Another branch of it (*a*, fig. 34) descends to the west, for a length of 250 feet, varying in thickness, but sometimes more than 20 feet deep: it is then cut off by the small river Orcia, as some glaciers in Switzerland descend into a valley till their progress is suddenly arrested by a transverse stream of water.

The abrupt termination of the mass of rock, at the river where its thickness is undiminished, clearly shows that it would proceed much farther if not arrested by the stream, over which it impends slightly. But it cannot encroach upon the channel of the Orcia, being constantly undermined, so that its solid fragments are seen strewed amongst the alluvial gravel. However enormous, therefore, the mass of solid rock may appear which has been given out by this single spring, we may feel assured that it is insignificant in volume when compared to that which has been carried to the sea since the time it began to flow. What may have been the length of that period of time we have no data for conjecturing. In quarrying the travertin, Roman tiles have been sometimes found at the depth of five or six feet.

Baths of San Filippo.—On another hill, not many miles from that last mentioned, and also connected with Mount Amiata, the summit of which is about three miles distant, are the celebrated baths of San Filippo. The subjacent rocks consist of alternations of black slate, limestone, and serpentine. There are three warm springs containing carbonate and sulphate of lime, and sulphate of magnesia. The water which supplies the baths falls into a pond, where it has been known to deposit a solid mass *thirty feet thick* in about *twenty years*.* A manufactory of medallions in basso-relievo is carried on at these baths. The water is conducted by canals into several pits, in which it deposits travertin and crystals of sulphate of lime. After being thus freed from its grosser parts, it is conveyed by a tube to the summit of a small chamber, and made to fall through a space of ten or

* Dr. Grosse on the Baths of San Filippo, Ed. Phil. Journ. vol. ii. p. 292.

twelve feet. The current is broken in its descent by numerous crossed sticks, by which the spray is dispersed around upon certain moulds, which are rubbed lightly over with a solution of soap, and a deposition of solid matter like marble is the result, yielding a beautiful cast of the figures formed in the mould. The geologist may derive from these experiments considerable light, in regard to the high slope of the strata at which some semi-crystalline precipitations can be formed; for some of the moulds are disposed almost perpendicularly, yet the deposition is nearly equal in all parts.

Spheroidal structure in travertin.—Travertin of Tivoli.—But what renders this recent limestone of peculiar interest to the geologist, is the spheroidal form which it assumes, analogous to that of the cascade of Tivoli (see fig. 35), in the neighbourhood of Rome. Here the calcareous waters of the Anio incrust the reeds which grow on its banks, and the foam of the cataract of Tivoli forms beautiful pendent stalactites. On the sides of the deep chasm into which the cascade throws itself there is seen an extraordinary accumulation of horizontal beds of tufa and travertin, from four to five hundred feet in thickness. The section immediately under the temples of Vesta and the Sibyl displays, in a precipice about four hundred feet high, some spheroids which are from *six to eight feet in diameter*, each concentric layer being about the eighth of an inch in thickness. The following diagram exhibits about fourteen feet of this immense mass, as seen in the path cut out of the rock in descending from the temple of Vesta to the Grotto di Nettuno. I have not attempted to express in this drawing the innumerable thin layers of which these magnificent spheroids are composed, but the lines given mark some of the natural divisions into which they are separated by minute variations in the size or colour of the laminæ. The undulations also are much smaller in proportion to the whole circumference than in the drawing. The beds (*a a*) are of hard travertin and soft tufa; below them is a pisolite (*b*), the globules being of different sizes: underneath this appears a mass of concretionary travertin (*c c*), some of the spheroids being of the above-mentioned extraordinary size. In some

places (as at *d*) there is a mass of amorphous limestone, or tufa, surrounded by concentric layers. At the bottom is another bed of pisolite (*b*), in which the small nodules are about the size and shape of beans, and some of them of filberts, intermixed with some smaller oolitic grains. In the tufaceous strata, wood is seen converted into a light tufa.

Fig. 35.

Section of spheroidal concretionary travertin under the Cascade of Tivoli.

The lamination of some of the concentric masses is so minute that sixty may be counted in the thickness of an inch; yet, notwithstanding these marks of gradual and successive deposition, sections are sometimes exhibited of what might seem to be perfect spheres. This tendency to a mammillary and globular structure arises from the facility with which

the calcareous matter is precipitated in nearly equal quantities on all sides of any fragment of shell or wood, or any inequality of the surface over which the mineral water flows, the form of the nucleus being readily transmitted through any number of successive envelopes. But these masses can never be perfect spheres, although they often appear such when a transverse section is made in any line not in the direction of the point of attachment. There are, indeed, occasionally seen small oolitic and pisolitic grains, of which the form is globular: for the nucleus, having been for a time in motion in the water, has received fresh accessions of matter on all sides.

In the same manner I have seen, on the vertical walls of large steam boilers, the heads of nails or rivets covered by a series of enveloping crusts of calcareous matter, usually sulphate of lime; so that a concretionary nodule is formed, preserving a nearly globular shape, when increased to a mass several inches in diameter. In these, as in many travertins, there is often a combination of the concentric and radiated structure.

There can be little doubt that the whole of this deposit was formed in an extensive lake which existed at the close of the period of volcanic activity by which the lavas and tuffs of the Roman territory were formed. The external configuration of the country has since been greatly changed, and the Anio now throws itself into a ravine excavated in the ancient travertin. Its waters give rise to masses of calcareous stone, scarcely if at all distinguishable from the older rock. I was shown, in 1828, in the upper part of the travertin, the hollow left by a cart-wheel, in which the outer circle and the spokes had been decomposed, and the spaces which they filled left void. It seemed to me at the time impossible to explain the position of this mould, without supposing that the wheel was imbedded before the lake was drained; but Sir R. Murchison suggests that it may have been washed down by a flood into the gorge in modern times, and then incrusted with calcareous tufa in the same manner as the wooden beam of the church of St. Lucia was swept down in 1826, and stuck fast in the Grotto of the Syren,

where it still remains, and will eventually be quite imbedded in travertin.*

Campagna di Roma.—The country around Rome, like many parts of the Tuscan States already referred to, has been at some former period the site of numerous volcanic eruptions; and the springs are still copiously impregnated with lime, carbonic acid, and sulphuretted hydrogen. A hot spring was discovered about 1827, near Civita Vecchia, by Signor Riccioli, which deposits alternate beds of a yellowish travertin, and a white granular rock, not distinguishable, in hand specimens, either in grain, colour, or composition, from statuary marble. There is a passage between this and ordinary travertin. The mass accumulated near the spring is in some places about six feet thick.

Lake of the Solfatara.—In the Campagna, between Rome and Tivoli, is the Lake of the Solfatara, called also Lago di Zolfo (*lacus albula*), into which flows continually a stream of tepid water from a smaller lake, situated a few yards above it. The water is a saturated solution of carbonic acid gas, which escapes from it in such quantities in some parts of its surface, that it has the appearance of being actually in ebullition. 'I have found by experiment,' says Sir Humphry Davy, 'that the water taken from the most tranquil part of the lake, even after being agitated and exposed to the air, contained in solution more than its own volume of carbonic acid gas, with a very small quantity of sulphuretted hydrogen. Its high temperature, which is pretty constant at 80° of Fahr., and the quantity of carbonic acid that it contains, render it peculiarly fitted to afford nourishment to vegetable life. The banks of travertin are everywhere covered with reeds, lichen, confervæ, and various kinds of aquatic vegetables; and at the same time that the process of vegetable life is going on, the crystallisations of the calcareous matter, which is everywhere deposited, in consequence of the escape of carbonic acid, likewise proceed. There is, I believe, no place in the world where there is a more striking example of the opposition or contrast of the laws of animate and inanimate nature, of the

* Murchison, Geol. Quart. Journ. 1850, vol. vi. p. 293.

forces of inorganic chemical affinity, and those of the powers of life.' *

The same observer informs us that he fixed a stick in a mass of travertin covered by the water in the month of May, and in April following he had some difficulty in breaking, with a sharp-pointed hammer, the mass which adhered to the stick, and which was several inches in thickness. The upper part was a mixture of light tufa and the leaves of confervæ; below this was a darker and more solid travertin, containing black and decomposed masses of confervæ; in the inferior part the travertin was more solid, and of a grey colour, but with cavities probably produced by the decomposition of vegetable matter.†

The stream which flows out of this lake fills a canal about nine feet broad and four deep, and is conspicuous in the landscape by a line of vapour which rises from it. It deposits calcareous tufa in this channel, and the Tiber probably receives from it, as well as from numerous other streams, much carbonate of lime in solution, which may contribute to the rapid growth of its delta. A large proportion of the most splendid edifices of ancient and modern Rome are built of travertin, derived from the quarries of Ponte Lucano, where there has evidently been a lake at a remote period, on the same plain as that already described.

Sulphureous and gypseous springs.—The quantity of other mineral ingredients wherewith springs in general are impregnated is insignificant in comparison to lime, and this earth is most frequently combined with carbonic acid. But, as sulphuric acid and sulphuretted hydrogen are very frequently supplied by springs, gypsum may, perhaps, be deposited largely in certain seas and lakes. Among other gypseous precipitates at present known on the land, I may mention those of Baden, near Vienna, from the springs which feed the public bath. Some of these supply singly from 600 to 1,000 cubic feet of water per hour, and deposit a fine powder, composed of a mixture of sulphate of lime with sulphur and muriate of lime.‡ The thermal waters of Aix,

* Consolidation of Travel, pp. 123–125.

† Ibid. p. 127.

‡ C. Prevost, Essai sur la Constitution physique du Bassin de Vienne, p. 10.

in Savoy, in passing through strata of Jurassic limestone, turn them into gypsum or sulphate of lime. In the Andes, at the Puenta del Inca, Lieutenant Brand found a thermal spring at the temperature of 91° Fahr., containing a large proportion of gypsum with carbonate of lime and other ingredients.* Many of the mineral springs of Iceland, says Professor Bunsen, deposit gypsum,† and sulphureous acid gas escapes plentifully from them as from the volcanos of the same island. It may, indeed, be laid down as a general rule, that the mineral substances, as before stated, dissolved in hot springs agree very closely with those which are disengaged in a gaseous form from the craters of active volcanos.

Siliceous springs.—Azores.—In order that water should hold a very large quantity of silica in solution, it seems necessary that it should be raised to a high temperature.‡ The hot springs of the Valle das Fernas, in the island of St. Michael, rising through volcanic rocks, precipitate vast quantities of siliceous sinter. Around the circular basin of the largest spring, which is between twenty and thirty feet in diameter, alternate layers are seen of a coarser variety of sinter mixed with clay, including grass, ferns, and reeds, in different states of petrifaction. In some instances, alumina, which is likewise deposited from the hot waters, is the mineralising material. Branches of the same ferns which now flourish in the island are found completely petrified, preserving the same appearance as when vegetating, except that they acquire an ash-grey colour. Fragments of wood, and an entire stratum from three to five feet thick, composed of reeds now common in the island, have become completely mineralised.

The most abundant variety of siliceous sinter occurs in layers, from a quarter to half an inch in thickness, accumulated on each other often to the height of a foot and upwards, and constituting parallel, and for the most part horizontal, strata many yards in extent. This sinter has often a beautiful semi-opalescent lustre. A recent breccia is also in the

* Travels across the Andes, p. 240.

† Annalen der Chem. 1847.

‡ Daubeny on Volcanoes, p. 222.

act of forming, composed of obsidian, pumice, and scoriæ, cemented by siliceous sinter.*

Geysers of Iceland.—The origin of the Icelandic geysers, or the cause of the intermittent play of those thermal fountains, will be fully considered in Chap. XXXIII. when volcanic action is treated of. I shall merely allude to them here as illustrating the deposition of silex now in progress.† The circular reservoirs into which the geysers fall, are lined in the interior with a variety of opal, and round the edges with sinter. The plants incrusted with the latter substance have much the same appearance as those incrusted with calcareous tufa in our own country. They consist of various grasses, the horse-tail (*Equisetum*), and leaves of the birch-tree, which are the most common of all, though no trees of this species now exist in the surrounding country. The petrified stems also of the birch occur in a state much resembling agatised wood.‡

By analysis of the water, Faraday ascertained that the solution of the silex is promoted by the presence of the alkali, soda. He suggested that the deposition of silica in an insoluble state takes place partly because the water when cooled by exposure to the air is unable to retain as much silica as when it issues from the earth at a temperature of 180° or 190° Fahr., and partly because the evaporation of the water decomposes the compound of silica and soda which previously existed. This last change is probably hastened by the carbonic acid of the atmosphere uniting with the soda. The alkali, when disunited from the silica, would readily be dissolved in and removed by running water.§

Mineral waters, even when charged with a small proportion of silica, as those of Ischia, may supply certain species of corals, sponges, and infusoria with matter for their siliceous secretions; but there is little doubt that rivers obtain silex in solution from another and far more general source, namely, the decomposition of felspar. When this mineral,

* Dr. Webster on the Hot Springs of Furnas, Ed. Phil. Journ. vol. vi. p. 306.

† See a cut of the Icelandic geyser, Chap. XXXIII.

‡ M. Robert, Bulletin de la Soc. Géol. de France, tom. vii. p. 11.

§ Barrow's Iceland, p. 209.

which is so abundant an ingredient in the hypogene and trappean rocks, has disintegrated, it is found that the residue, called porcelain clay, contains but a small proportion of the silica which existed in the original felspar, the other part having been dissolved and removed by water.*

Ferruginous springs.—The waters of almost all springs contain some iron in solution; and it is a fact familiar to all, that many of them are so copiously impregnated with this metal, as to stain the rocks or herbage through which they pass, and to bind together sand and gravel into solid masses. We may naturally, then, conclude that this iron, which is constantly conveyed from the interior of the earth into lakes and seas, and which does not escape again from them into the atmosphere by evaporation, must act as a colouring and cementing principle in the subaqueous deposits now in progress. Geologists are aware that many ancient sandstones and conglomerates are bound together or coloured by iron.

Brine springs.—So great is the quantity of chloride of sodium in some springs, that they yield one fourth of their weight in salt. They are rarely, however, so saturated, and generally contain, intermixed with salt, carbonate and sulphate of lime, magnesia, and other mineral ingredients. The brine springs of Cheshire are the richest in our country; those of Northwich being almost saturated. There are others also in Lancashire and Worcestershire which are extremely rich.† They are known to have flowed for more than 1,000 years, and the quantity of salt which they have carried into the Severn and Mersey must be enormous. These brine springs rise up through strata of sandstone and red marl, which contain large beds of rock salt. The origin of the brine, therefore, may be derived in this and many other instances from beds of fossil salt; but, as chloride of sodium is one of the products of volcanic emanations and of springs in volcanic regions, the original source of salt may be as deep-seated as that of lava.

Many springs in Sicily contain muriate of soda, and the

* See Lyell's Elements of Geology; and Dr. Turner, Jam. Ed. New Phil. Journ. No. xxx. p. 246.

† L. Horner, Geol. Trans. vol. iii. p. 94.

'fiume salso,' in particular, is impregnated with so large a quantity, that cattle refuse to drink of it. A hot spring rising through granite, at Saint Nectaire, in Auvergne, may be mentioned as one of many, containing a large proportion of salt, together with magnesia and other ingredients.*

Carbonated springs.—Auvergne.—Carbonic acid gas is very plentifully disengaged from springs in almost all countries, but particularly near active or extinct volcanos. It has the property of decomposing many of the hardest rocks with which it comes in contact, particularly that numerous class in whose composition felspar is an ingredient. It renders the oxide of iron soluble in water, and contributes, as was before stated, to the solution of calcareous matter. In volcanic districts these gaseous emanations are not confined to springs, but rise up in the state of pure gas from the soil in various places. The Grotto del Cane, near Naples, affords an example, and prodigious quantities are now annually disengaged from every part of the Limagne d'Auvergne, where it appears to have been plentifully evolved from time immemorial As the acid is invisible, it is not observed, except an excavation be made, wherein it often accumulates, so that it will extinguish a candle. There are some springs in this district where the water is seen bubbling and boiling up with much noise, in consequence of the abundant disengagement of this gas. In the environs of Pont Gibaud, not far from Clermont, a rock belonging to the gneiss formation, in which lead-mines are worked, has been found to be quite saturated with carbonic acid gas, which is constantly disengaged. The carbonates of iron, lime, and manganese are so dissolved, that the rock is rendered soft, and the quartz alone remains unattacked.† Not far off is the small volcanic cone of Chaluzet, which once broke up through the gneiss, and sent forth a lava-stream.

Disengagement of free carbonic acid.—Prof. Bischoff, in his history of volcanos,‡ has shown what enormous quantities of

* Ann. de l'Auvergne, tom. i. p. 234.

† Ann. Scient. de l'Auvergne, tom. ii. June 1829.

‡ Edinb. New Phil. Journ. Oct. 1839.

carbonic acid gas are exhaled in the vicinity of the extinct craters of the Rhine (in the neighbourhood of the Laacher-see, for example, and the Eifel), and also in the mineral springs of Nassau and other countries, where there are no such traces of modern volcanic action. It would be easy to calculate in how short a period the solid carbon thus emitted from the interior of the earth in an invisible form, would amount to a quantity as great as could be obtained from the trees of a large forest, and how many thousand years would be required to supply the materials of a dense seam of pure coal from the same source. I have already alluded (p. 226) to the doctrine favoured by some geologists of the existence of an atmosphere highly charged with carbonic acid, at the period of the ancient coal-plants, and have endeavoured to show that the opinion is untenable.* We have no right to draw such an inference as to the former chemical constitution of the atmosphere, until we have data for estimating the volume of carbonic acid gas emitted from the earth in volcanic regions, or given out by dead animal and vegetable substances during putrefaction, and comparing it with the volume of the same gas annually extracted from the air, and afterwards stored up in the earth's crust in the form of peat, buried timber, and organic matter derived from the animal kingdom.

Disintegrating effects of carbonic acid.—The disintegration of granite is a striking feature of large districts in Auvergne, especially in the neighbourhood of Clermont. This decay was called by Dolomieu 'la maladie du granite.' The phenomenon may, without doubt, be ascribed to the continual disengagement of carbonic acid gas from numerous fissures.

In the plains of the Po, between Verona and Parma, especially at Villa Franca, south of Mantua, I observed great beds of alluvium, consisting chiefly of pebbles of crystalline rock, percolated by spring-water, charged with carbonate of lime and carbonic acid in great abundance. They are for the most part incrusted with calc-sinter; and the rounded blocks of gneiss, which have all the outward appearance of

* See Lyell's Travels in N. America. June 1829.

solidity, and which could only have acquired their shape by trituration when extremely hard, have been so disintegrated by the carbonic acid as readily to fall to pieces.

The subtraction of many of the elements of rocks by the solvent power of carbonic acid, ascending both in a gaseous state and mixed with spring-water in the crevices of rocks, must be one of the most active sources of those internal changes and rearrangements of particles so often observed in strata of every age. The calcareous matter, for example, of shells, is often entirely removed and replaced by carbonate of iron, pyrites, silex, or some other ingredient, such as mineral waters usually contain in solution. It rarely happens, except in limestone rocks, that the carbonic acid can dissolve all the constituent parts of the mass; and for this reason, probably, calcareous rocks are almost the only ones in which great caverns and long winding passages are found.

Petroleum springs.—Springs of which the waters contain a mixture of petroleum, or rock oil, which is a compound of hydrogen and carbon, and the various minerals allied to it, such as naphtha and asphalt or mineral pitch, are very numerous. All these substances, says Mr. T. Sterry Hunt, are forms of bitumen, some, like petroleum, being fluid, others, like asphalt, being solid at ordinary temperatures. They are supposed to be all of organic origin, derived partly from terrestrial, partly from marine plants, and sometimes from animal remains; for portions, says Mr. Hunt, of the tissues of various marine animals of low grade are destitute of nitrogen, and very similar in mineral composition to the woody fibre of plants. The probability, in some cases, of an animal origin has been especially inferred from the abundance of animal remains, and the paucity of those of plants in the beds containing them.* Petroleum is found in formations of every age, from the Lower Silurian up to the Tertiary; but a large number of the oil-wells of the United States, which have lately attracted so much attention, are in Devonian and Silurian rocks.

In some instances the petroleum appears to filter slowly into the wells from the porous strata around, which are satu-

* Judd's Letter, Dec. 3, 1874.

rated with it, while at other times the boring instrument seems to strike upon a fissure communicating with a reservoir which furnishes at once great volumes of oil.*

The great pitch lake of Trinidad is situated, according to Mr. Wall, in Tertiary strata, chiefly Upper Miocene, but partly, perhaps, Lower Pliocene. The asphalt is derived from bituminous shales, containing vegetable remains, which are sometimes seen in the process of transformation, with their organic structure more or less obliterated. Occasionally the bituminous substance becomes plastic and even oily, and rises to the surface.† Such changes from oil to a pitch may be brought about, says Mr. T. S. Hunt, partly by the evaporation of the volatile ingredients, and partly by oxidation from the air.

Captain Mallet observes that, near Cape La Braye, in the island of Trinidad, fluid bitumen sometimes oozes out from the bottom of the sea, and rises to the surface. The same author quotes Gumilla, as stating, in his 'Description of the Orinoco,' that, 'about seventy years ago, a spot of land on the western coast of Trinidad, near half-way between the capital and an Indian village, sank suddenly, and was immediately replaced by a small lake of pitch, to the great terror of the inhabitants.'‡

A similar subsidence, at an earlier period, may probably have given rise to the great pitch lake of Trinidad, the cavity having become gradually filled with asphalt. Every geologist is familiar with the odour emitted from what are called fetid limestones when first broken. The Niagara limestone of the Upper Silurian group in America is sometimes so impregnated with bitumen, that this substance, when the stone is burned for lime, flows from the kiln like tar.§

* Sterry Hunt, Canadian Naturalist, vol. vi. p. 245. August, 1861.

† Wall. Quart. Geol. Journ. vol. xvi. p. 468. 1860.

‡ Mallet, cited by Dr. Nugent, Geol. Trans. vol. i. p. 69. 1811.

§ T. S. Hunt, ibid. p. 245.

CHAPTER XVIII.

REPRODUCTIVE EFFECTS OF RIVERS.

LAKE DELTAS—GROWTH OF THE DELTA OF THE UPPER RHONE IN THE LAKE OF GENEVA—PLAYFAIR ON THE ORIGIN OF LAKE BASINS—COMPUTATION OF THE AGE OF DELTAS—RECENT DEPOSITS IN LAKE SUPERIOR—DELTAS OF INLAND SEAS—COURSE OF THE PO—ARTIFICIAL EMBANKMENTS OF THE PO AND ADIGE—DELTA OF THE PO, AND OTHER RIVERS ENTERING THE ADRIATIC—RAPID CONVERSION OF THE GULF INTO LAND—MINERAL CHARACTERS OF THE NEW DEPOSITS—MARINE DELTA OF THE RHONE—VARIOUS PROOFS OF ITS INCREASE—STONY NATURE OF ITS DEPOSITS—COAST OF ASIA MINOR —DELTA OF THE NILE—CHRONOLOGICAL COMPUTATION OF THE GROWTH OF THE NILE MUD AT MEMPHIS.

DELTAS IN LAKES.

I HAVE already spoken in the fourteenth chapter of the action of running water, and of the denuding power of rivers, but we can only form a just conception of the excavating and removing force exerted by such bodies of water, when we have the advantage of examining the reproductive effects of the same agents: in other words, of beholding in a palpable form the aggregate amount of matter which they have thrown down at certain points in their alluvial plains, or in the basins of lakes and seas. Yet it will appear, when we consider the action of currents, that the growth of deltas affords a very inadequate standard by which to measure the entire carrying power of running water, since a considerable portion of fluviatile sediment is swept far out to sea.

Deltas may be divided into, first, those which are formed in lakes; secondly, those in inland seas, where the tides are almost imperceptible; and, thirdly, those on the borders of the ocean. The most characteristic distinction between the lacustrine and marine deltas consists in the nature of the organic remains which become imbedded in their deposits;

for, in the case of a lake, it is obvious that these must consist exclusively of such genera of animals as inhabit the land or the waters of a river or lake; whereas, in the other case, there will be an admixture, and most frequently a predominance, of animals which inhabit salt water. In regard, however, to the distribution of inorganic matter, the deposits of lakes and seas are formed under very analogous circumstances.

Lake of Geneva.—Lakes exemplify the first reproductive operations in which rivers are engaged when they convey the detritus of rocks and the ingredients of mineral springs from higher to lower regions. The accession of new land at the mouth of the Rhone, at the upper end of the Lake of Geneva, or the Leman Lake, presents us with an example of a considerable thickness of strata which have accumulated since the historical era. This sheet of water is about 1,200 feet above the sea, thirty-seven miles long, and its breadth is from two to eight miles. The shape of the bottom is very irregular, the depth having been found to vary from 20 to 160 fathoms.* The Rhone, where it enters at the upper end, is turbid and discoloured; but its waters, where it issues at the town of Geneva, are beautifully clear and transparent. An ancient town, called Port Vallais (Portus Valesiæ of the Romans), once situated at the water's edge, at the upper end, is now more than a mile and a half inland—this intervening alluvial tract having been acquired in about eight centuries. The remainder of the delta consists of a flat alluvial plain, about five or six miles in length, composed of sand and mud, a little raised above the level of the river, and full of marshes.

Sir Henry De la Beche found, after numerous soundings in all parts of the lake, that there was a pretty uniform depth of from 120 to 160 fathoms throughout the central region, and on approaching the delta the shallowing of the bottom began to be very sensible at a distance of about a mile and three-quarters from the mouth of the Rhone; for a line drawn from St. Gingoulph to Vevey gives a mean depth of somewhat less than 600 feet, and from that part to the

* De la Beche, Ed. Phil. Journ. vol. ii. p. 107. Jan. 1820.

Rhone, the fluviatile mud is always found along the bottom.* We may state, therefore, that the new strata annually produced are thrown down upon a slope about two miles in length; so that, notwithstanding the great depth of the lake, the new deposits are inclined at so slight an angle, that they would be termed, in ordinary geological language, horizontal.

The strata probably consist of alternations of finer and coarser particles; for, during the hotter months from April to August, when the snows melt, the volume and velocity of the river are greatest, and large quantities of sand, mud, vegetable matter, and drift-wood are introduced; but during the rest of the year the influx is comparatively feeble, so much so, that the whole lake, according to Saussure, stands six feet lower. If, then, we could obtain a section of the accumulation formed in the last eight centuries, we should see a great series of strata, probably from 600 to 900 feet thick, and nearly two miles in length, inclined at a very slight angle. A much more considerable deposit of similarly stratified matter, of an age antecedent to the historical, would be seen extending to the original head of the lake five or six miles distant from the accumulations of the last 800 years. Simultaneously with the growth of the principal delta, a great number of rapid torrents are bringing down large masses of sand and pebbles, and forming smaller deltas at their mouths round the borders of the lake. The body of water in such torrents is too small to enable them to spread out the transported matter over so extensive an area as the Rhone does. Thus, for example, there is a depth of eighty fathoms within half a mile of the shore, immediately opposite the great torrent which enters east of Ripaille, so that the dip of the strata in that minor delta must be about four times as great as that of the deposits formed by the main river at the upper extremity of the lake.†

The capacity of this basin being now ascertained, it would be an interesting subject of enquiry, to determine in what number of years the Leman Lake will be converted into dry land. It would not be very difficult to obtain the elements

* De la Beche, MS.

† Ibid.

for such a calculation, so as to approximate at least to the quantity of time required for the accomplishment of the result. The number of cubic feet of water annually discharged by the river into the lake being estimated, experiments might be made in the winter and summer months, to determine the proportion of matter held in suspension or in chemical solution by the Rhone. It would be also necessary to allow for the heavier matter drifted along at the bottom, which might be estimated on hydrostatic principles, when the average size of the gravel and the volume and velocity of the stream at different seasons were known. Supposing all these observations to have been made, it would be more easy to calculate the future than the former progress of the delta, because it would be a laborious task to ascertain, with any degree of precision, the original depth and extent of that part of the lake which is already filled up. Even if this information were actually obtained by borings, it would only enable us to approximate within a certain number of centuries to the time when the Rhone began to form its present delta; but this would not give us the date of the origin of the Leman Lake in its present form, because the river may have flowed into it for thousands of years, without importing any sediment whatever. Such would have been the case, if the waters had first passed through a chain of upper lakes; and that this was actually the fact, seems indicated by the course of the Rhone between Martigny and the Lake of Geneva, and, still more decidedly, by the channels of many of its principal feeders.

If we ascend, for example, the valley through which the Dranse flows, we find that it consists of a succession of basins, one above the other, in each of which there is a wide expanse of flat alluvial lands, separated from the next basin by a rocky gorge, once perhaps the barrier of a lake. The river seems to have filled these lakes, one after the other, and to have partially cut through the barriers, some of which it is still gradually eroding to a greater depth. Before, therefore, we can pretend even to hazard a conjecture as to the era at which the principal delta of Lake Leman or any other delta commenced, we must be thoroughly acquainted

with the geographical features and geological history of the whole system of higher valleys which communicate with the main stream, and all the changes which they have undergone since the last series of convulsions which agitated and altered the face of the country.

Playfair, in his 'Illustrations of the Huttonian Theory of the Earth,' after declaring that he agreed in opinion with the Scotch geologist that the principal valleys of the Alps and other mountains have been excavated by rivers, frankly admits that the Lake of Geneva seems to offer an objection to that theory. The valley above is so deep and broad, that the materials removed from it ought to have filled up the lake again and again 'on any reasonable supposition concerning its original magnitude.' What has become of all the materials which the Rhone has brought down from the higher region? To explain away the difficulty, he suggests, among other hypotheses, that the lake had no existence while the river was eroding the valley above. Part, both of the rising and sinking of the land, he observes, has happened within periods comparatively modern. 'The elevations and depressions may not be the same for every spot; they may be partial, and one part of a stratum or body of strata may rise to a greater height or be more depressed than another. It is not impossible that this process may affect the depth of lakes and change the relative level of their sides and bottom.* 'The Vallais,' he also adds, 'which we consider as the work of the Rhone, may not have owed all its inequalities to the running of water. It may, when the Alps rose out of the sea, have included many depressions of the surface which the river joined together, and from being a series of lakes formed into one great valley.' † A suggestion has lately been made, that the rock-basin which the Lake of Geneva fills may have been scooped out by ice. That it was once occupied by a glacier I fully admit, but that the action of the glacier hollowed out the cavity is an hypothesis which appears to me quite untenable, for reasons which I have explained elsewhere.‡

* Playfair. Illustrations of Huttonian Theory, p. 366.

† Ibid. p. 367.

‡ Elements of Geology, edition of 1865, p. 170; and Student's Elements, p. 160.

Lake Superior.—Lake Superior is the largest body of fresh water in the world, being above 1,700 geographical miles in circumference when we follow the sinuosities of its coasts, and its length, on a curved line drawn through its centre, being more than 400, and its extreme breadth above 150 geographical miles. Its surface is nearly as large as the whole of England proper. Its average depth varies from 80 to 150 fathoms; but, according to Captain Bayfield, there is reason to think that its greatest depth would not be overrated at 200 fathoms, so that its bottom is, in some parts, nearly 600 feet below the level of the Atlantic, its surface being about as much above it. There are appearances in different parts of this, as of the other Canadian lakes, leading us to infer that its waters formerly occupied a higher level than they reach at present; for at a considerable distance from the present shores, parallel lines of rolled stones and sand are seen rising one above the other, like the seats of an amphitheatre. These ancient lines of shingle are exactly similar to the present beaches in most bays, and they often attain an elevation of 40 or 50 feet, and sometimes several hundred feet, above the present level. The heaviest gales of wind do not raise the water more than three or four feet, and the loose materials, says Agassiz, which lie within the action of heavy storms, are entirely deprived of vegetation, whereas the set of beaches next above are covered by a few cryptogamous and herbaceous plants. At a still higher level, and retreating more and more from the shores, are terraces on which grow shrubs and small trees, and above these older beaches are precipitous banks cut out of loose materials, which must have been worn for a considerable time by the action of the waves. Six, ten, and even fifteen such terraces may sometimes be distinguished one above the other. All these beaches and terraces are composed of remodelled glacial drift, the stones having lost more or less of their scratches and polished appearance, and having been rolled into ordinary pebbles. M. Agassiz, when discussing the question how so many changes may have been produced in the level of the old shore of the lake, inclines to the opinion that the land has

risen unequally, rather than that the waters have been repeatedly lowered by the successive wearing down or removal of the barrier on the side where it is lowest at present.* If we are compelled to grant that such inequalities of movement have occurred in Post-glacial times, we may well suppose that others of far greater extent contributed, before and during the Glacial period, to form the basin of the great lake itself.

The streams which discharge their waters into Lake Superior, without reckoning many of smaller size, are several hundred in number; and the quantity of water supplied by them is many times greater than that discharged at the Falls of St. Mary, the only outlet. The evaporation, therefore, is very great, and such as might be expected from so vast an extent of surface. On the northern side, which is encircled by mountains of old crystalline rock, the rivers sweep in many large boulders with smaller gravel and sand, chiefly composed of granitic and trap rocks. There are also currents in the lake in various directions, caused by the continual prevalence of strong winds, and to their influence we may attribute the diffusion of finer mud far and wide over great areas; for by numerous soundings made during Capt. Bayfield's survey, it was ascertained that the bottom consists generally of a very adhesive clay, containing shells of the species at present existing in the lake. When exposed to the air, this clay immediately becomes so indurated as to require a smart blow of the hammer to break it. It effervesces slightly with diluted nitric acid, and is of different colours in different parts of the lake; in one district blue, in another red, and in a third white, hardening into a substance resembling pipeclay.† From these statements, the geologist will not fail to remark how closely these recent lacustrine formations in America resemble the tertiary argillaceous and calcareous marls of lacustrine origin in Central France. In both cases many of the genera of shells most abundant, as Lymnea and Planorbis, are the same; and in regard to other

* Agassiz, Lake Superior, p. 416.

† Trans. of Lit. and Hist. Soc. of Quebec, vol. i. p. 5. 1829.

classes of organic remains there must be the closest analogy, as I shall endeavour more fully to explain when speaking of the imbedding of plants and animals in recent deposits.

DELTAS OF INLAND SEAS.

Having thus briefly considered some of the lacustrine deltas now in progress, we may next turn our attention to those of inland seas.

Deltas of the Po and Adige.—The Po affords an instructive example of the manner in which a great river bears down to the sea the matter poured into it by a multitude of tributaries descending from lofty chains of mountains. It has been calculated by Mr. Geikie that this river removes one foot of rock from the general surface of its basin in 729 years.* The changes gradually effected in the great plain of Northern Italy since the time of the Roman republic are considerable. Extensive lakes and marshes have been gradually filled up, as those near Placentia, Parma, and Cremona, and many have been drained naturally by the deepening of the beds of rivers. Deserted river-courses are not unfrequent, as that of the Serio Morto, which formerly fell into the Adda, in Lombardy. The Po also itself has often deviated from its course, having, after the year 1390, deserted part of the territory of Cremona, and invaded that of Parma; its old channel being still recognisable, and bearing the name of Po Morto. There is also an old channel of the Po in the territory of Parma, called Po Vecchio, which was abandoned in the twelfth century, when a great number of towns were destroyed.

To check these and similar aberrations, a general system of embankment has been adopted; and the Po, Adige, and almost all their tributaries, are now confined between high artificial banks. The increased velocity acquired by streams thus closed in, enables them to convey a much larger portion of foreign matter to the sea; and, consequently, the deltas of the Po and Adige have gained far more rapidly on the Adriatic since the practice of embankment became almost universal. But, although more sediment is borne to the sea,

* Trans. Geol. Soc. of Glasgow, 1868, vol. iii. p. 164.

part of the sand and mud, which in the natural state of things would be spread out by annual inundations over the plain, now subsides in the bottom of the river-channels; and, their capacity being thereby diminished, it is necessary, in order to prevent inundations in the following spring, to extract matter from the bed, and to add it to the banks of the river. Hence it happens that these streams now traverse the plain on the top of high mounds, like the waters of aqueducts, and at Ferrara the surface of the Po has become more elevated than the roofs of the houses.* The magnitude of these barriers is a subject of increasing expense and anxiety, it having been sometimes found necessary to give an additional height of nearly one foot to the banks of the Adige and Po in a single season.

The practice of embankment was adopted on some of the Italian rivers as early as the thirteenth century; and Dante, writing in the beginning of the fourteenth, describes, in the seventh circle of hell, a rivulet of tears separated from a burning sandy desert by embankments 'like those which, between Ghent and Bruges, were raised against the ocean, or those which the Paduans had erected along the Brenta to defend their villas on the melting of the Alpine snows.'

Quale i Fiamminghi tra Guzzante e Bruggia,
  Temendo il fiotto che in ver lor s' avventa,
  Fanno lo schermo, perchè il mar si fuggia;
E quale i Padovan lungo la Brenta,
  Per difender lor ville e lor castelli,
  Anzi che Chiarentana il caldo senta.

Inferno, Canto xv.

In the Adriatic, from the northern part of the Gulf of Trieste, where the Isonzo enters, down to the south of Ravenna, there is an uninterrupted series of recent accessions of land, more than 100 miles in length, which within the last 2,000 years has increased from *two to twenty miles in breadth.* A line of sand-bars of great length has been formed nearly all along the western coast of this gulf, inside of which are lagunes, such as those of Venice, and the large lagune of Comacchio, 20 miles in diameter. Newly

* Prony, see Cuvier, Disc. prélim. p. 146.

deposited mud brought down by the streams is continually lessening the depth of the lagunes, and converting part of them into meadows.* The Isonzo, Tagliamento, Piave, Brenta, Adige, and Po, besides many other inferior rivers, contribute to this advance of the coast-line and to the shallowing of the lagunes and the gulf.

The Po and the Adige may now be considered as entering by one common delta, for two branches of the Adige are connected with arms of the Po, and thus the principal delta has been pushed out beyond those bars which separate the lagunes from the sea. The rate of the advance of this new land has been accelerated, as before stated, since the system of embanking the rivers became general, especially at that point where the Po and Adige enter. The waters are no longer permitted to spread themselves far and wide over the plains, and to leave behind them the larger portion of their sediment. Mountain torrents also have become more turbid since the clearing away of forests, which once clothed the southern flanks of the Alps. It is calculated that the mean rate of advance of the delta of the Po on the Adriatic between the years 1200 and 1600 was 25 yards or metres a year, whereas the mean annual gain from 1600 to 1804 was 70 metres.†

Adria was a seaport in the time of Augustus, and had, in ancient times, given its name to the gulf; it is now about twenty Italian miles inland. Ravenna was also a seaport, and is now about four miles from the main sea. Yet, even before the practice of embankment was introduced, the alluvium of the Po advanced with rapidity on the Adriatic; for Spina, a very ancient city, originally built in the district of Ravenna, at the mouth of a great arm of the Po, was, so early as the commencement of our era, eleven miles distant from the sea.‡

But although so many rivers are rapidly converting the Adriatic into land, it appears, by the observations of M. Morlot, that since the time of the Romans there has been a

* See De Beaumont, Géologie pratique, vol. i. p. 323. 1844.

† Prony, cited by Cuvier, Discours prélim.

‡ Brocchi, Conch. Foss. Subap. vol. i. p. 118.

general subsidence of the coast and bed of this sea in the same region to the amount of five feet, so that the advance of the new-made land has not been so fast as it would have been had the level of the coast remained unaltered. The signs of a much greater depression anterior to the historical period have also been brought to light by an Artesian well, bored at Venice in 1847, to the depth of more than 400 feet, which still failed to penetrate through the modern fluviatile deposit. The auger passed chiefly through beds of sand and clay; but at four several depths, one of them very near the bottom of the excavation, it pierced beds of turf, or accumulations of vegetable matter, precisely similar to those now formed superficially on the extreme borders of the Adriatic. Hence we learn that a considerable area of what was once land has sunk down 400 feet in the course of ages.*

The greatest depth of the Adriatic, between Dalmatia and the mouths of the Po, is twenty-two fathoms; but a large part of the Gulf of Trieste and the Adriatic, opposite Venice, is less than twelve fathoms deep. Farther to the south, where it is less affected by the influx of great rivers, the gulf deepens considerably. Donati, after dredging the bottom, discovered the new deposits to consist partly of mud and partly of rock, the rock being formed of calcareous matter, incrusting shells. He also ascertained that particular species of testacea were grouped together in certain places, and were becoming slowly incorporated with the mud or calcareous precipitates.† Olivi, also, found some deposits of sand, and others of mud, extending half-way across the gulf; and he states that their distribution along the bottom was evidently determined by the prevailing current.‡ It is probable, therefore, that the finer sediment of all the rivers at the head of the Adriatic may be intermingled by the influence of the current; and all the central parts of the gulf may be considered as slowly filling up with horizontal deposits, similar to those of the Subapennine hills, and containing many of the same species of shells. The Po merely introduces at present fine

* Archiac. Histoire des Progrès de la Géol. 1848, vol. ii. p. 232.

† Brocchi, Conch. Foss. Subap. vol. i. p. 39.

‡ Ibid. vol. ii. p. 94

sand and mud, for it carries no pebbles farther than the spot where it joins the Trebia, west of Piacenza. At the northern borders of the Gulf of Trieste, the Isonzo, Tagliamento, and many other streams, are forming immense beds of sand and some conglomerate; for here some high mountains of Alpine limestone approach within a few miles of the sea.

In the time of the Romans, the hot baths of Monfalcone were on one of several islands of Alpine limestone, between which and the mainland, on the north, was a channel of the sea, about a mile broad. This channel is now converted into a grassy plain, which surrounds the island on all sides. Among the numerous changes on this coast, we find that the present channel of the Isonzo is several miles to the west of its ancient bed, in part of which, at Ronchi, the old Roman bridge which crossed the Via Appia was lately found buried in fluviatile silt.

Marine delta of the Rhone.—The lacustrine delta of the Rhone in Switzerland has already been considered (p. 413); its contemporaneous marine delta may now be described. Scarcely has the river passed out of the Lake of Geneva before its pure waters are again filled with sand and sediment by the impetuous Arve, descending from the highest Alps, and bearing along in its current the granitic sand and impalpable mud annually brought down by the glaciers of Mont Blanc. The Rhone afterwards receives vast contributions of transported matter from the Alps of Dauphiny, and the primary and volcanic mountains of Central France; and when at length it enters the Mediterranean, it discolours the blue waters of that sea with a whitish sediment, for the distance of between six and seven miles, throughout which space the current of fresh water is perceptible.

Strabo's description of the delta is so inapplicable to its present configuration, as to attest a complete alteration in the physical features of the country since the Augustan age. It appears, however, that the head of the delta, or the point at which it begins to ramify, has remained unaltered since the time of Pliny, for he states that the Rhone divided itself at Arles into two arms. This is the case at present; one of the branches, the western, being now called Le Petit Rhone,

which is again subdivided before entering the Mediterranean. The advance of the base of the delta, in the last eighteen centuries, is demonstrated by many curious antiquarian monuments. The most striking of these is the great and unnatural détour of the old Roman road from Ugernum to Beziers (*Bœterræ*), which went round by Nismes (*Nemausus*). It is clear that, when this was first constructed, it was impossible to pass in a direct line, as now, across the delta, and that either the sea or marshes intervened in a tract now consisting of terra firma.* Astruc also remarks, that all the places on low lands, lying to the north of the old Roman road between Nismes and Beziers, have names of Celtic origin, evidently given to them by the first inhabitants of the country; whereas, the places lying south of that road, towards the sea, have names of Latin derivation, and were clearly founded after the Roman language had been introduced.

Another proof, also, of the great extent of land which has come into existence since the Romans conquered and colonised Gaul, is derived from the fact, that the Roman writers never mention the thermal waters of Balaruc in the delta, although they were well acquainted with those of Aix, and others still more distant, and attached great importance to them, as they invariably did to all hot springs. The waters of Balaruc, therefore, must have formerly issued under the sea —a common phenomenon on the borders of the Mediterranean; and on the advance of the delta they continued to flow out through the new deposits.

Among the more direct proofs of the increase of land, we find that Mese, described under the appellation of Mesua Collis by Pomponius Mela,† and stated by him to be nearly an island, is now far inland. Notre-Dame des Ports, also, was a harbour in 898, and is now two leagues from the shore. Psalmodi was an island in 815, and is now two leagues from the sea. Several old lines of towers and sea-marks occur at different distances from the present coast, all indicating the successive retreat of the sea, for each line has in its turn

* Mém. d'Astruc, cited by Von Hoff, vol. i. p. 288.

† Lib. ii. c. v.

become useless to mariners; which may well be conceived, when we state that the Tower of Tignaux, erected on the shore so late as the year 1737, is already a mile remote from it.*

By the confluence of the Rhone and the currents of the Mediterranean, driven by winds from the south, sand-bars are often formed across the mouths of the river: by these means considerable spaces become parted off from the sea, and subsequently from the river also, when it shifts its channels of efflux. As some of these lagunes are subject to the occasional ingress of the river when flooded, and of the sea during storms, they are alternately salt and fresh. Others, after being filled with salt water, are often lowered by evaporation till they become more salt than the sea; and it has happened, occasionally, that a considerable precipitate of chloride of sodium has taken place in these natural salterns. During the latter part of Napoleon's career, when the excise laws were enforced with extreme rigour, the police was employed to prevent such salt from being used. The fluviatile and marine shells inclosed in these small lakes often live together in brackish water; but the uncongenial nature of the fluid usually produces a dwarfish size, and sometimes gives rise to strange varieties in form and colour.

Captain Smyth, in his survey of the coast of the Mediterranean, found the sea, opposite the mouth of the Rhone, to deepen gradually from four to forty fathoms, within a distance of six or seven miles, over which the discoloured fresh water extends. The inclination of the new deposits must be too slight to be appreciable, the slope being about a tenth of that already mentioned in the Lake of Geneva (p. 413), which would appear to the eye, in sections of the length usually exhibited in quarries, as horizontal. When the wind blew from the south-west, the ships employed in the survey were obliged to quit their moorings; and when they returned, the new sand-banks in the delta were found covered over with a great abundance of marine shells. By this means we learn how occasional beds of drifted marine shells may become interstratified with fresh-water strata at a river's mouth.

* Bouche, Chorographie et Hist. de Provence, vol. i. p. 23, cited by Von Hoff, vol. i. p. 290.

Stony nature of its deposits.—That a great proportion, at least, of the new deposit in the delta of the Rhone consists of *rock*, and not of loose incoherent matter, is perfectly ascertained. In the Museum at Montpelier is a cannon taken up from the sea near the mouth of the river, imbedded in a crystalline calcareous rock. Large masses, also, are continually taken up of an arenaceous rock, cemented by calcareous matter including multitudes of broken shells of recent species. The observations in the nineteenth century made on this subject corroborate the former statement of Marsilli in the eighteenth, that the earthy deposits of the coast of Languedoc form a stony substance, for which reason he ascribes a certain bituminous, saline, and glutinous nature to the substances brought down with sand by the Rhone.* If the number of mineral springs charged with carbonate of lime which fall into the Rhone and its feeders in different parts of France be considered, we shall feel no surprise at the lapidification of the newly-deposited sediment in this delta. It should be remembered, that the fresh water introduced by rivers, being lighter than the water of the sea, floats over the latter, and remains upon the surface for a considerable distance. Consequently it is exposed to as much evaporation as the waters of a lake; and the area over which the river water is spread, at the junction of great rivers and the sea, may well be compared, in point of extent, to that of considerable lakes.

Now, it is well known, that so great is the quantity of water carried off by evaporation in some lakes, that it is nearly equal to the water flowing in; and in some inland seas, as the Caspian, it is quite equal. We may, therefore, well suppose that, in cases where a strong current does not interfere, the greater portion not only of the matter held mechanically in suspension, but of that also which is in chemical solution, may be precipitated at no great distance from the shore. When these finer ingredients are extremely small in quantity, they may only suffice to supply crustaceous animals, corals, and marine plants, with the earthy particles necessary for their secretions; but whenever it is in excess (as generally happens if the basin of a river lie partly in a district of active

* Hist. phys. de la Mer.

or extinct volcanos), then will solid deposits be formed, and the shells will at once be included in a rocky mass.

Deposits on the coast of Asia Minor.—Examples of the advance of the land upon the sea are afforded by the southern coast of Asia Minor. Admiral Sir F. Beaufort has pointed out in his survey the great alterations effected since the time of Strabo, where havens are filled up, islands joined to the mainland, and where the whole continent has increased many miles in extent. Strabo himself, on comparing the outline of the coast in his time with its ancient state, was convinced, like our countryman, that it had gained very considerably upon the sea. The new-formed strata of Asia Minor consist *of stone*, not of loose incoherent materials. Almost all the streamlets and rivers, like many of those in Tuscany and the south of Italy, hold abundance of carbonate of lime in solution, and precipitate travertin, or sometimes bind together the sand and gravel into solid sandstones and conglomerates. Every delta and sand-bar thus acquires solidity, which often prevents streams from forcing their way through them, so that their mouths are constantly changing their position.*

Delta of the Nile.—That Egypt was 'the gift of the Nile,' was the opinion of her priests before the time of Herodotus; and there can be no doubt that the fertility of the alluvial plain above Cairo, and the very existence of the delta below that city, are due to the action of the great river, or to its power of transporting mud from the interior of Africa, and depositing it on its inundated plains, as well as on that space which has been reclaimed from the Mediterranean, and converted into land.

The depth of the Mediterranean is about twelve fathoms at a small distance from the shore of the delta; it afterwards increases gradually to 50, and then suddenly descends to 380 fathoms. We learn from Lieut. Newbold that nothing but the finest and lightest ingredients reach the Mediterranean, where he has observed the sea discoloured by them to the distance of 40 miles from the shore.† The small

* Karamania, or a brief description of the Coast of Asia Minor, &c. London, 1817.

† Quart. Journ. Geol. Soc. 1848, vol. iv. p. 342.

progress of the delta in the last 2,000 years affords, perhaps, no measure for estimating its rate of growth before it had encroached so much upon the coast-line of the Mediterranean. A powerful current now sweeps along the shores of Africa, from the Straits of Gibraltar to the prominent convexity of Egypt, the western side of which is continually the prey of the waves; so that not only are fresh accessions of land checked, but ancient parts of the delta are carried away. By this cause Canopus and some other towns have been overwhelmed. The marine current alluded to is caused by the prevalence for nine months of the year of winds from the north-west, but they turn in the opposite direction whenever, during the remaining months, a wind sets in from the east. Another reason, however, for the slow advance of the delta for the last two or three thousand years, is the slow subsidence of the land, to which allusion will be made in the sequel.

The Nile for the last 1,500 miles of its course is not joined by a single tributary, great or small; a geographical peculiarity exhibited by no other river in the world. In Nubia however, during violent thunderstorms, temporary torrents are sometimes formed, some of them as low down as between the first and second cataracts, which wash gravel sand, and mud into the Nile. The winds also blow clouds of sand into it from the desert where the valley is narrow above the first cataract. About 100 miles above Cairo, or 200 from the sea, the average width of the valley is about five miles; and I am informed by the Rev. Barham Zincke, who has lately returned from Egypt (1871), that the bluffs which bound the plain on the east and west, are composed, some of them of limestone and some of sandstone, and are about 400 feet high. In sailing up the stream for about 450 miles sometimes the eastern and sometimes the western bluff is in sight, and they conveyed to him the appearance of having been cut by the Nile, as if the river had excavated its own valley. But when we arrive at the first cataract at Assouan the rocks, being formed of granite, seem to have afforded greater resistance to the erosive power of the river, which there flows through a narrow gorge instead of a wide alluvial plain.

In passing through so many degrees of latitude exposed o a hot sun and to arid winds blowing from the surround- ng deserts, the river loses much of its water by evapora- ion, especially where it is spread out over the plains during he season of inundation, which lasts about four months. he sediment annually left behind on the plain consists of n extremely thin film of matter, most of the mud being hrown down on the banks, which here, as in all other great ivers, are higher than the flat region between them and he heights bounding the valley on each side, so that during he flood season the banks are seen alone emerging above he waters, and forming two long narrow strips of land. he base of the delta is more than 200 miles in length, if e include in it all that part of the coast which intervenes etween the ancient extreme eastern and western arms; but hese are blocked up at present; and that part of the coast-line, bout 90 miles in length, which extends from the Rosetta to he Damietta branches is the only portion now usually called he Delta. The diameter of this low tract from south to orth, or from the coast to the head of the delta near Cairo or to the ancient site of Memphis, thirty miles distant on he other side of the river), is about 100 miles. In this re- ion the rate of the deposition of sediment is considerably ss than in the alluvial plain above, owing to the wide spread f the waters east and west. The height of the river at ssouan or the ancient Philæ, where the first cataract occurs, s 300 feet above its level at Cairo, a distance of 555 statute iles, following the course of the river, which gives an ave- ge fall of rather more than half a foot (6·486 inches) er mile; but the fall between the head of the delta and the ea is much less considerable. According to Sir J. G. Wil- inson, the alluvial matter formed in 1,700 years on the land bout Elephantine, or near the first cataract, lat. 24° 5′, is bout 9 feet in thickness; at Thebes, lat. 25° 43′, about feet in the same period; and at Heliopolis and Cairo, t. 30°, about 5 feet 10 inches; and the amount is consider- bly less at Rosetta and the other mouths of the Nile, t. 31° 30′.

The bed of the Nile always keeps pace with the general levation of the soil of Egypt; and the river-banks, like

those of the Mississippi and its tributaries (see p. 439), are much higher than the flat land at a distance, so that they are seldom covered, as before mentioned (p. 429), during the highest inundations. In consequence of the gradual rise of the river's bed, the annual flood is continually spreading over a wider area, and the alluvial soil encroaches on the desert, covering, to the depth of several feet or yards, the base of statues and temples which the waters never reached 3,000 years ago. Although the sands of the Libyan deserts have in some places been drifted into the valley of the Nile, yet these aggressions, says Wilkinson, are far more than counterbalanced by the fertilising effect of the water which now reaches further inland towards the desert, so that the number of square miles of arable soil is greater at present than at any previous period.

The composition of the Nile-mud resembles very closely that of the Loess or old inundation mud of the Rhine. The following careful analysis is given of it by Lassaigne:* Silica, 42·50; alumina, 24·25; carbonate of lime, 3·85; peroxide of iron, 13·65; magnesia, 1·05; carbonate of magnesia, 1·20; humic acid, 2·80; water, 10·70. It was shown by recent borings, which will presently be mentioned, to be very generally devoid of stratification, except near the margin of the valley, where violent winds have blown quartzose sand from the adjacent deserts, so as to cause alternations of sand and loam in thin layers. It is also stated that around Cairo, where artificial excavations have been made, or in other places where the river has undermined its banks, the mud is divided into layers of different colours, each of them not exceeding a sheet of thin pasteboard in thickness.

The late Mr. L. Horner, F.R.S., was of opinion that the general absence of all indication of successive deposition might be attributed to the extreme thinness of the layer of matter annually thrown down on the greater part of the alluvial plain. The tenuity of this layer is such as not to average, according to the best observers, six inches in a century. The new superficial deposit, which is added to a soil already softened by a submergence of several months,

* Quart. Geol. Journ. 1849, vol. v. p. 20. Memoirs.

must be indistinguishable from it. Deep shrinkage cracks are formed both in the new and old soil, where they have been exposed to a hot sun, and into these is drifted dust, raised in clouds by the winds. The action also of worms, insects, and the roots of plants, must be added to these disturbing causes, so that it is evident that no distinction can be left between the deposits of two successive years, even at points where the labours of the agriculturist have not intervened to annihilate all lines of separation.

As the pyramids and other monuments of Egypt carry us back to prehistoric times of more ancient date than do any equally authentic memorials yet known in other lands, it is there, if anywhere, that we may hope to obtain data for estimating roughly at least the number of years which have been required to bring about a given amount of change in the alluvial plain of a great river.

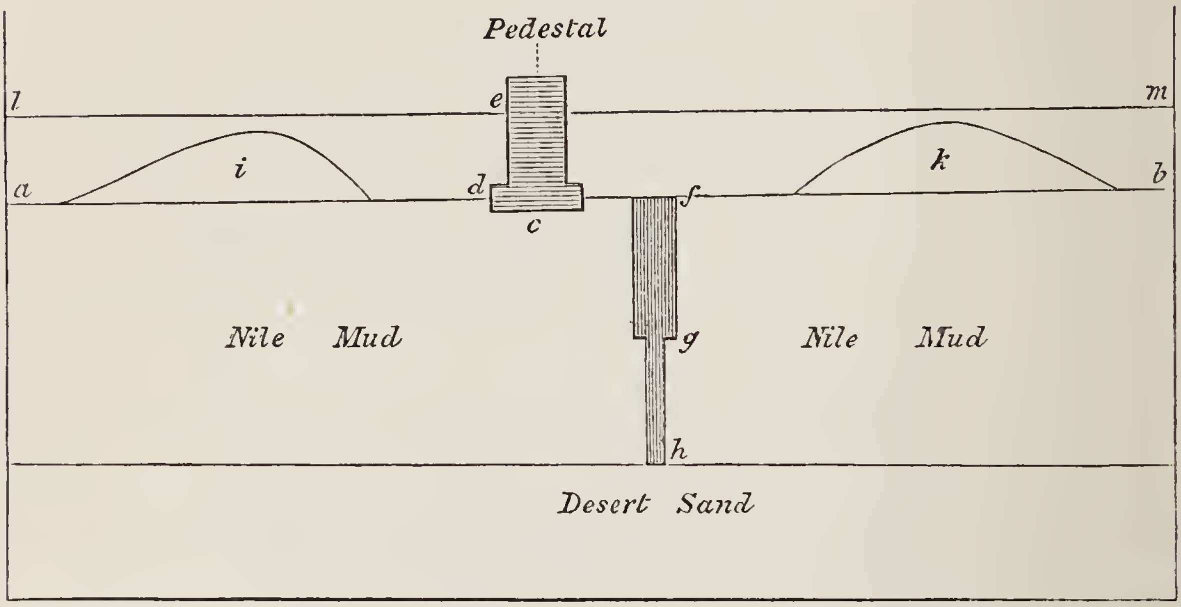
Herodotus observes, 'that the country round Memphis seemed formerly to have been an arm of the sea gradually filled by the Nile, in the same manner as the Meander, Achelous, and other streams, had formed deltas. Egypt, therefore,' he says, 'like the Red Sea, was once a long narrow bay, and both gulfs were separated by a small neck of land. If the Nile,' he adds, 'should by any means have an issue into the Arabian Gulf, it might choke it up with earth in 20,000 or even, perhaps, in 10,000 years; and why may not the Nile have filled a still greater gulf with mud in the space of time which has passed before our age?' *

Mr. Horner suggested to the Royal Society, in 1850, that they should have excavations and borings made in the alluvial plain of the Nile, with a view of ascertaining the thickness of the mud which had accumulated round the base of the obelisk at Heliopolis and the pedestal of the statue of Rameses at Memphis, the object being to obtain a chronometric scale, by ascertaining what thickness of sediment had been formed in a given time, and applying that scale for measuring the antiquity of similar mud previously thrown down on the site of those monuments before their erection. The most important result was obtained from an

* Euterpe, XI.

excavation and boring made near the base of the pedestal of the colossal statue of Rameses, the middle of whose reign, according to Lepsius, was 1361 years B.C. Assuming with Mr. Horner * that the lower part of the platform or foundation c (fig. 36) was $14\frac{3}{4}$ inches below the surface of the ground, or alluvial flat a b, at the time it was laid, there had been formed between that period and the year A.D. 1850, or

Fig. 36.



Section to explain the thickness of Nile mud on the site of the pedestal of the statue of Rameses at Memphis.

a b. Supposed level of the great Plain when the foundation of the pedestal was laid.
c. Level of lowest part of foundation of pedestal.
d e. Thickness of mud accumulated since the erection of the pedestal.
f g. Shaft, 16 ft. deep, sunk near the pedestal.
g h. Boring carried down 14 ft. below the bottom of the shaft to the junction of the Nile mud with the underlying desert sand.
i k. Mounds thrown up to protect the area of the Temple from the inundations of the Nile.
l m. Present level of the alluvial plain of the Nile.

during a space of 3,211 years, a deposit of 9 feet 4 inches from d to e round the pedestal, which gives a mean increase of $3\frac{1}{2}$ inches in a hundred years. It was farther ascertained, by sinking a shaft f g near the pedestal, and by a boring in the same place carried to the additional depth g h, that below the level of the old plain a b the thickness of old Nile

* Horner, On Alluvial Land of Egypt, Phil. Trans. part i. for 1855.

mud *f h* resting on desert sand amounted to 32 feet; and it was therefore inferred by Mr. Horner that the lowest layer at *h* (in which a fragment of burnt brick was found) was more than 13,000 years old, or was deposited 13,496 years before the year 1850, when the boring was made.

The date of the reign of Rameses has been a matter of discussion; but, even if antiquaries should differ by a few centuries, the era fixed by Lepsius may be taken as a sufficient approximation to the truth to be available for the object here proposed.

To this mode of computation it was objected by Mr. Samuel Sharpe, that the Egyptians were in the habit of enclosing with embankments such as *i k*, fig. 36, the areas on which they erected temples and statues, so as to exclude the waters of the Nile. Herodotus tells us that in his time those spots from which the Nile waters had in this manner been shut out for centuries appeared sunk, and could be looked down into from the surrounding ground, that ground having been raised by the gradual accumulation of sediment resulting from the annual inundations. The whole thickness therefore *d e* of 9 feet 4 inches of mud in which the pedestal of the statue was buried, instead of indicating 3,215 years, is simply the produce of the much shorter period which has elapsed since Memphis fell into decay, or since the mounds *i k* gave way and allowed the river to inundate the site of the statue. But Sir John Lubbock, in reply to this objection, has truly remarked that what we are really in search of is the extent to which the flat plain of Memphis *l m* has been raised by the accumulation of Nile sediment since the statue was erected; and although the river when it broke through the embankments and washed mud from them into the enclosure might perhaps in a few years raise the enclosed area up to the level of the great plain outside *l m*, yet it could never heighten that area above the general level. The exceptional rapidity of accumulation, observes Sir J. Lubbock, would only be the complement of the exceptional want of deposition which had preceded.*

Mr. A. R. Wallace, on reading my Antiquity of Man, p. 36,

* Sir J. Lubbock, The Reader, March 26, 1864.

sent me this same answer to Mr. Sharpe's objection, which had occurred to him independently. The explanation will perhaps remove some of the difficulties which Mr. Franks and other antiquaries experienced in regard to the date assigned by Mr. Horner, in accordance with his scale, to several pieces of sculpture and pottery found at different levels in sinking through the ten feet of soil *e d*, in which the lower part of the pedestal was buried. It is most desirable, however, that fresh enquiries should be made to extend and verify the observations already so successfully begun by Mr. Horner, with the assistance of a native engineer, Hekekyan Bey, and under the auspices of the Royal Society, liberally assisted by the late Viceroy of Egypt.

In all calculations referring to the growth of alluvial deposits, or to the effects of aqueous denudation, our chief difficulty in geology arises from our inability to measure correctly the accompanying movements of the land. The position of certain tombs near Alexandria, and their present level relatively to the Mediterranean, and the ruins of certain towns half submerged in the Lake Menzaleh, are generally admitted to imply that there has been a sinking of the land in Egypt within the historical period.

The occurrence of former oscillations of level is also attested by the existence, at different heights, from 30 to 100 feet and upwards, above the level of the present alluvial plain, of a succession of terraces composed of fluviatile alluvium. In these Messrs. Adams and Murie have detected fossil shells of the same species as those now inhabiting the waters of the Nile, such as *Ætheria semilunata*, *Iridina nilotica*, *Bulimus pullus*, and *Cyrena fluminalis*. The last-mentioned shell is familiar to us as being so common in the ancient or Post-pliocene river-deposits of the Thames, in London and the neighbourhood, in which the bones of a hippopotamus and other extinct animals are found.

Such terraces occur both above and below the first cataract; in one of them, at Kálábshé in Nubia, the molar teeth of a large hippopotamus were obtained, and were identified by the late Dr. Falconer with the species now living in the Nile.

These and other proofs of gradual movements which have occurred in Post-tertiary times, in Egypt, might have been looked for by geologists, after they had come by independent researches to the conclusion, that the northern borders of the Red Sea and a large part of the Sahara, or, in other words, vast regions east and west of Egypt, had been upraised within the Post-pliocene epoch. On the one side is the Great Desert, formerly submerged beneath the sea, and now laid dry,* with the *Cardium edule* frequently strewn over its surface; on the other side, or to the eastward, are littoral deposits 200 feet high, bordering the western shore of the Red Sea (lat. 28° N.), which are chiefly made up of corals and shells of recent species, indicating a modern conversion of the ancient sea-bottom into land. During such great continental movements we cannot suppose the intervening valley of the Nile to have remained stationary in its level, or that the great river never shifted its position, and never deepened its channel, whether cutting through accumulations of its own mud, or through subjacent rocks of sandstone and granite.

* Elements of Geology, p. 174.

CHAPTER XIX.

REPRODUCTIVE EFFECTS OF RIVERS—*continued.*

DELTAS FORMED UNDER THE INFLUENCE OF TIDES—BASIN AND DELTA OF THE MISSISSIPPI—ALLUVIAL PLAIN—RIVER-BANKS AND BLUFFS—CURVES OF THE RIVER—NATURAL RAFTS AND SNAGS—MUD-LUMPS NEAR THE MOUTHS, AND THEIR PROBABLE ORIGIN—NEW LAKES, AND EFFECTS OF EARTHQUAKES—ANTIQUITY OF THE DELTA—SECTION IN ARTESIAN WELL AT NEW ORLEANS—DELTA OF THE AMAZONS—DELTA OF THE GANGES AND BRAHMAPOOTRA—HEAD OF THE DELTA AND SUNDERBUNDS—ISLANDS FORMED AND DESTROYED—CROCODILES—AMOUNT OF FLUVIATILE SEDIMENT IN THE WATER—ARTESIAN BORING AT CALCUTTA—PROOFS OF SUBSIDENCE—AGE OF THE DELTA—CONVERGENCE OF DELTAS—ORIGIN OF EXISTING DELTAS NOT CONTEMPORANEOUS—GROUPING OF STRATA AND STRATIFICATION IN DELTAS—CONGLOMERATES—CONSTANT INTERCHANGE OF LAND AND SEA.

In the last chapter several examples were given of the deltas of inland seas, where the influence of the tides is almost imperceptible. We may next consider those marine or oceanic deltas, where the tides play an efficient part in the dispersion of fluviatile sediment, as in the Gulf of Mexico, where they exert a moderate degree of force, and in the Bay of Bengal, where they are extremely powerful. In regard to estuaries, which Rennell termed 'negative deltas,' they will be treated of more properly when our attention is specially turned to the operations of tides and currents in the 21st, 22nd, and 23rd chapters. In this case, instead of the land gaining on the sea at the river's mouth, the tides penetrate far inland beyond the general coast-line.

BASIN AND DELTA OF THE MISSISSIPPI.

Extent of the basin.—The hydrographical basin of the Mississippi displays, on the grandest scale, the action of running water on the surface of a vast continent. This magnificent river rises nearly in the forty-ninth parallel of north latitude, and flows to the Gulf of Mexico in the twenty-ninth—a

course, including its meanders, of more than 3,000 miles. It passes from a cold climate, where the hunter obtains his furs and peltries, traverses the temperate latitudes, and discharges its waters into the sea in the region of rice, the cotton-plant, and the sugar-cane. From near its mouth at the Balize a steamboat may ascend for 2,000 miles with scarcely any perceptible difference in the width of the river. Several of its tributaries, the Red River, the Arkansas, the Missouri, the Ohio, and others, would be regarded elsewhere as of the first importance, and, taken together, are navigable for a distance many times exceeding that of the main stream. The surface drained by the Mississippi and its tributaries is equal in extent to more than half the continent of Europe, or Europe exclusive of Russia, Norway, and Sweden.

No river affords a more striking illustration of the law before mentioned, that an augmentation of volume does not occasion a proportional increase of surface, nay, is even sometimes attended with a narrowing of the channel. The Mississippi is half a mile wide at its junction with the Missouri, the latter being also of equal width; yet the united waters have only, from their confluence to the mouth of the Ohio, a medial width of about half a mile. The junction of the Ohio seems also to produce no increase, but rather a decrease, of surface.* The St. Francis, White, Arkansas, and Red rivers are also absorbed by the main stream with scarcely any apparent increase of its width, although here and there it expands to a breadth of $1\frac{1}{2}$, or even to 2 miles. On arriving at New Orleans, it is somewhat less than half a mile wide. Its depth there is very variable, the greatest at high water being 168 feet. The mean rate at which the whole body of water flows is variously estimated; according to Mr. Forshey the mean velocity of the current at the surface somewhat exceeds $2\frac{1}{4}$ miles an hour when the water is at a mean height. Messrs. Humphreys and Abbot found at Natchez a velocity of nearly three miles an hour, at the depth of five feet from the surface. For 300 miles above New Orleans the distance measured by the winding river is about twice as great as the distance in a right line. For the

* Flint's Geography, vol. i. p. 142.

first 100 miles from the mouth the rate of fall is 1·80 inch per mile, for the second hundred 2 inches, for the third 2·30, for the fourth 2·57. Messrs. Humphreys and Abbot give about 4½ inches as the average fall per mile from Memphis to the mouth, a distance of 855 miles.

The alluvial plain of the Mississippi begins to be of great width below Cape Girardeau, 50 miles above the junction of the Ohio. At this junction it is about 50 miles broad, south of which it contracts to about 30 miles at Memphis, expands again to 80 miles at the mouth of the White River, and then suffers various contractions and expansions until it reaches the head of the delta, or the point where the Mississippi sends off its highest branch or arm, called the Atchafalaya. The delta has a diameter from N.W. to S.E. of about 200 miles, and a breadth in the opposite direction of about 140. It comprises, according to the survey of 1860, an area of about 12,300 miles, but to this I shall again refer.

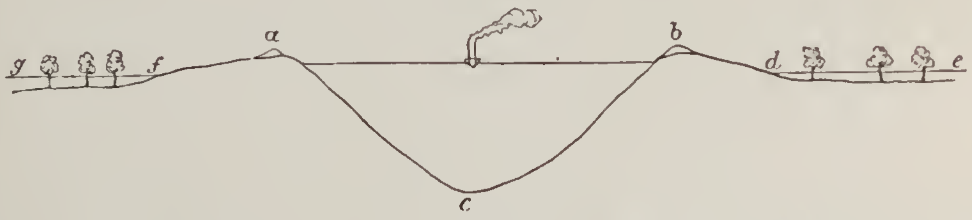
Curves of the Mississippi.—The river traverses the plain in a meandering course, describing immense curves. After sweeping round the half of a circle, it is carried in a rapid current diagonally across the ordinary direction of its channel, to another curve of similar shape. Opposite to each of these, there is always a sand-bar, answering, in the convexity of its form, to the concavity of 'the bend,' as it is called.* The river, by continually wearing these curves deeper, returns, in the manner before described (p. 341), on its own track, so that a vessel in some places, after sailing for twenty-five or thirty miles, is brought round again to within a mile of the place whence it started. When the waters approach so near to each other, it sometimes happens at high floods that they burst through the small tongue of land, and insulate a portion, rushing through what is called the 'cut-off,' so that vessels may pass from one point to another in half a mile to a distance which it previously required a voyage of more than twenty miles to reach. As soon as the river has excavated the new passage, bars of sand and mud are formed at the two points of junction with the old bend, which is soon entirely separated from the main

* Flint's Geog. vol. i. p. 152.

river by a continuous mud-bank covered with wood. The old bend then becomes a semicircular lake of clear water, inhabited by large gar-fish (*Lepidostei*), alligators, and wild fowl, which the steamboats have nearly driven away from the main river. A multitude of such crescent-shaped lakes, scattered far and wide over the alluvial plain, the greater number of them to the west, but some of them also eastward of the Mississippi, bear testimony to the extensive wanderings of the great stream in former ages. For the last two hundred miles above its mouth the course of the river is much less winding than above, there being only in the whole of that distance one great curve, that called the 'English Turn.' This greater straightness of the stream is ascribed by Mr. Forshey to the superior tenacity of the banks, which are more clayey in this region.

The Mississippi has been incorrectly described by some of the earlier geographers, as a river running along the top of

Fig. 37.



Section of channel, bank, levees (*a* and *b*), and swamps of Mississippi River.

a long hill, or mound in a plain. In reality it runs in a valley, from 100 to 200 or more feet in depth, as *a*, *c*, *b*, fig. 37, its banks forming long strips of land parallel to the course of the main stream, and to the swamps *g f* and *d e* lying on each side. These extensive morasses, which are commonly well wooded, though often submerged for months continuously, are rarely more than fifteen feet below the summit level of the banks. The banks themselves are occasionally overflowed, but are usually above water for a breadth of about two miles. They follow all the curves of the great river, and near New Orleans are raised artificially by embankments (or levees), of which sections are seen at *a* and *b*, fig. 37, through which the river when swollen sometimes cuts a deep channel (or crevasse), inundating the

adjoining low lands and swamps, and not sparing the lower streets of the great city.

The cause of the uniform upward slope of the river-bank, *d b*, above the adjoining alluvial plain is this: when the waters charged with sediment pass over the banks in the flood season, their velocity is checked among the herbage and reeds, and they throw down at once the coarser and more sandy matter with which they are charged. But the fine particles of mud are carried farther on, so that at the distance of two miles, a thin film of fine clay only subsides, forming a stiff unctuous black soil, which gradually envelops the base of trees growing on the borders of the swamps.

Waste of the banks.—It has been said of a mountain torrent, that 'it lays down what it will remove, and removes what it has laid down;' and in like manner the Mississippi, by the continual shifting of its course, sweeps away, during a great portion of the year, considerable tracts of alluvium, which were gradually accumulated by the overflow of former years, and the matter now left during the spring-floods will be at some future time removed. After the flood season, when the river subsides within its channel, it acts with destructive force upon the alluvial banks, softened and diluted by the recent overflow. Several acres at a time, thickly covered with wood, are precipitated into the stream; and large portions of the islands are frequently swept away.

Captain Hall, writing in 1829, observes that some years before, 'when the Mississippi was regularly surveyed, all its islands were numbered, from the confluence of the Missouri to the sea: but every season makes such revolutions, not only in the number but in the magnitude and situation of these islands, that this enumeration is now almost obsolete. Sometimes large islands are entirely melted away; at other places they have attached themselves to the main shore, or, which is the more correct statement, the interval has been filled up by myriads of logs cemented together by mud and rubbish.' *

Rafts.—One of the most interesting features in the great

* Travels in North America, vol. iii. p. 361.

rivers of this part of America is the frequent accumulation of what are termed 'rafts,' or masses of floating trees, which have been arrested on their progress by snags, islands, shoals, or other obstructions, and made to accumulate, so as to form natural bridges reaching entirely across the stream. One of the largest of these was called the raft of the Atchafalaya, an arm of the Mississippi, which branches off a short distance below its junction with the Red River. The Atchafalaya, being in a direct line with the general direction of the Mississippi, catches a large portion of the timber annually brought down from the north; and the drift trees collected in about thirty-eight years previous to 1816 formed a continuous raft, no less than ten miles in length, 220 yards wide, and eight feet deep. The whole rose and fell with the water, yet was covered with green bushes and trees, and its surface enlivened in the autumn by a variety of beautiful flowers. It went on increasing till about 1835, when some of the trees upon it had grown to the height of about sixty feet. Steps were then taken by the State of Louisiana to clear away the whole raft and open the navigation, which was effected, not without great labour, in the space of four years.

The rafts on Red River are equally remarkable; in some parts of its course, cedar trees are heaped up by themselves, and in other places pines. On the rise of the waters in summer hundreds of these are seen: some with their green leaves still upon them, just as they have fallen from a neighbouring bank; others leafless, broken, and worn in their passage from a far distant tributary. Wherever they accumulate on the edge of a sand-bar they arrest the current and soon become covered with sediment. On this mud the young willows and the poplars called cotton-wood spring up, their boughs still farther retarding the stream, and, as the inundation rises, accelerating the deposition of new soil. The bank continuing to enlarge, the channel at length becomes so narrow that a single long tree may reach from side to side, and the remaining space is then soon choked up by a quantity of other timber which has become waterlogged and has sunk to the bottom. This raft, say Messrs. Humphreys

and Abbot, formed a dam in 1860, which backed the Red River between twenty and thirty miles, and threw about three-quarters of its water through two natural outlets into Soda Lake, affording a navigation round the right bank of the raft.*

'Unfortunately for the navigation of the Mississippi,' observes Captain Hall, 'some of the largest trunks, after being cast down from the position on which they grew, get their roots entangled with the bottom of the river, where they remain anchored, as it were, in the mud. The force of the current naturally gives their tops a tendency downwards, and, by its flowing past, soon strips them of their leaves and branches. These fixtures, called snags, or planters, are extremely dangerous to the steam-vessels proceeding up the stream, in which they lie like a lance in rest, concealed beneath the water, with their sharp ends pointed directly against the bows of the vessels coming up. For the most part these formidable snags remain so still that they can be detected only by a slight ripple above them, not perceptible to inexperienced eyes. Sometimes, however, they vibrate up and down, alternately showing their heads above the surface, and bathing them beneath it.'† So imminent was the danger caused by these snags, that a steamboat was constructed and provided with machinery by which the greater number of these trunks of trees were drawn out of the mud.

The prodigious quantity of wood annually drifted down by the Mississippi and its tributaries is a subject of geological interest, not merely as illustrating the manner in which abundance of vegetable matter becomes, in the ordinary course of nature, imbedded in submarine and estuary deposits, but as attesting the constant destruction of soil and transportation of matter to lower levels by the tendency of rivers to shift their courses. Each of these trees must have required many years, some of them centuries, to attain their full size; the soil, therefore, whereon they grew, after remaining undisturbed for long periods, is ultimately torn up and swept away.

* Humphreys and Abbot, Report of Mississippi Survey, 1861.

† Travels in N. America, vol. iii. p. 362.

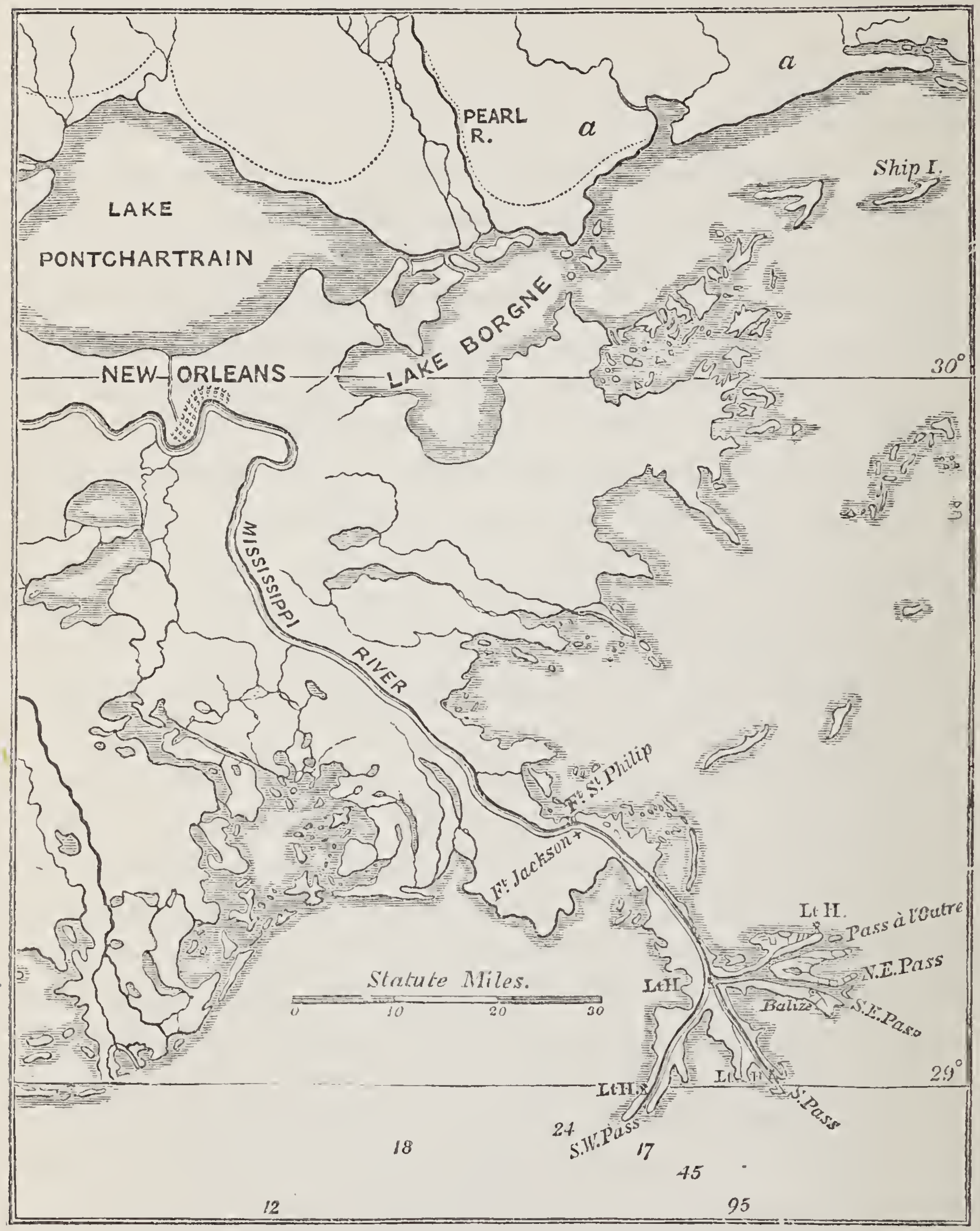
It is also found in excavating at New Orleans, even at the depth of several yards below the level of the sea, that the soil of the delta contains innumerable trunks of trees, layer above layer, some prostrate, as if drifted, others broken off near the bottom, but remaining still erect, and with their roots spreading on all sides, as if in their natural position. In such situations they appeared to me to indicate a sinking of the ground, as the trees must formerly have grown in marshes above the sea-level. In the higher parts of the alluvial plain, for many hundred miles above the head of the delta, similar stools and roots of trees are also seen buried in stiff clay at different levels, one above the other, and exposed to view in the banks at low water. They point clearly to the successive growth of forests in the extensive swamps of the plain, where the ground was slowly raised, year after year, by the mud thrown down during inundations. These roots and stools belong chiefly to the deciduous cypress (*Taxodium distichum*) and other swamp trees, and they bear testimony to the constant shifting of the course of the great river, which is always excavating land originally formed at some distance from its banks.

Mud-lumps off the mouths of the river.—The most southern or seaward part of the delta of the Mississippi is a long narrow tongue of land protruding itself for fifty miles into the Gulf of Mexico, and terminating in several arms or passes, as they are called, which have a fan-shaped arrangement (see map, fig. 38), the south-west pass being that through which all the water is now poured out, while each of the others has, by turns, at some former period, been the principal channel of discharge. The narrow tongue of land above alluded to consists simply of two low banks covered with reeds, young willows, and poplars.

In appearance these banks answer precisely to those of the river in the alluvial plain (see fig. 37, p. 439) when the inundation is at its height, and nothing is seen above water but the upper portions of the banks; but in the one case we have on each side a wide expanse of fresh water interrupted only by the tops of the tallest trees which grow in the swamps,

while in the other we have on each side the salt water of the Gulf of Mexico, of a bluish-green colour.

Fig. 38.



Map of part of the delta of the Mississippi below New Orleans.*

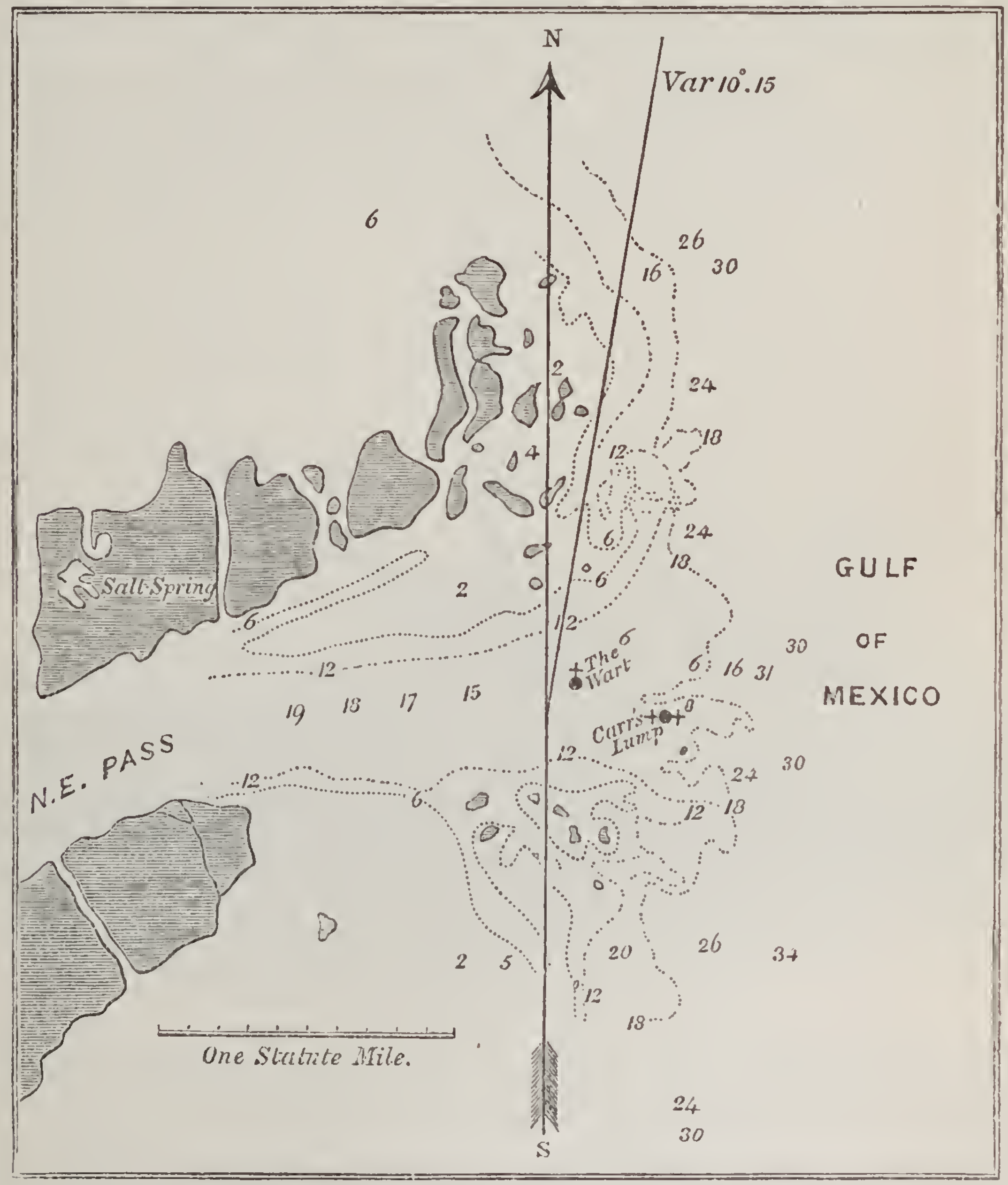
a, a. Post-Pliocene formation, partly marine and partly of cypress-swamp origin, called by Prof. Hilgard 'Coast-Pliocene.'

In this region, where so rapid a conversion is going on from sea into land, a phenomenon occurs which is without parallel,

* Humphreys and Abbot, Report on the Mississippi River, Plate II.

so far as I am aware, in the delta of any other river. I often heard, during my visit in 1845 to the pilot station called the Balize, of the swelling up of the muddy bottom of the gulf to the height of several feet, or even yards, above the level of high tide, and this in places where there had previously been

Fig. 39.



Map showing the positions of the Wart and Carr's Mud-lumps at the North-East Pass of the Mississippi River, from a survey of Capt. Talcott, in 1839.*

a depth of several fathoms. The pilots told me that these 'mud-lumps,' as they call them, sometimes displayed on their surface the anchors of vessels, and, in one instance, a cargo of

* This map and the views of the two mud-lumps were kindly communicated to me by Gen. Humphreys, of the U. S. Engineers.

heavy stones from a vessel which was known to have been wrecked in water ten feet deep. The island of the Balize originated in this manner, and five salt springs were described as rising in it, by certain French surveyors, as long ago as the year 1726.* Mr. Forshey states that, in 1832, a mud-island made its appearance, in the middle of which a spring issued. These new islands, as we learn from the subsequent survey of Captain Talcott in 1839, vary from an acre to several acres in extent. The gradual rise of some of them was watched during the survey, from two feet below water to three feet above it, and it was observed that *they were always situated*

Fig. 40.

S. View of Carr's Lump, N.E. Pass.
Extreme height above low water, 8 feet.

off some one of the mouths of the river. They have never been known to make their appearance in that part of the delta where no modern additions are being made to the land. Sometimes they attain a height of 10 or even 18 feet above the level of the sea (see figs. 40, 41). They are composed almost entirely of tenacious mud, usually homogeneous, but occasionally mixed with sand. This mud is chiefly pushed up bodily, but some of it consists of matter brought up by a spring to the top of the dome-shaped mass, and thrown down on the surface on all sides, over which the muddy water

* Thomassy, Bulletin de la Soc. Géol. de France, tom. xvii. p. 253. 1859–60.

pours. So much carburetted hydrogen or inflammable gas is emitted, together with salt or brackish water, that Col. Sidell suggests that they deserve the name of gas vents rather than of springs. The tubular cavities up which the springs rise are about 6 inches in diameter, vertical, and as regular in form as if bored by an auger. One which was sounded was found to be 24 feet deep, and the lead at the bottom of the line seemed to be still slowly sinking through thick mud. The springs issue at first from the centre and highest part, and afterwards successively through cracks at

Fig. 41.

S.S.W. View of the mud-lump called the Wart, N.E. Pass.
Extreme height above low water, 14 feet.

lower and lower levels, and in some of the oldest mud-lumps they have altogether ceased to flow.

During storms, when the surface of the gulf is raised by the prevalence of certain winds, the salt water is blown into the passes, and the waves undermine parts of these mud-lumps. The steepness and occasional verticality of the sides in the Wart and Carr's Lump (figs. 40 and 41) are due to such denuding action. Hurricanes have been known to sweep away an entire mud-lump, or at least such portions of it as

projected above low water. Col. Sidell informs me, that when an excavation was made at New Orleans for the foundation of the Custom House, some years after the survey of 1839, the digging appeared to him to be in the body of an old mud-lump;* and no doubt many such would be found in the older parts of the delta, and they would present a very perplexing enigma to a geologist who had no clue to their mode of origin. We learn from Professor Hilgard† that in 1862 Mr. D. H. Avery found on the coast of Louisiana, at a distance of 140 geographical miles from the mouth of the Mississippi, a deposit of rock-salt of very modern, perhaps post-Tertiary, age. It occurred in a little island called Petit Anse, which rises partly from the sea and partly from the coast-marsh. As this salt formation is said to be 144 acres in extent and 38 feet thick, it may perhaps be more or less continuous under the delta and be connected with the salt springs in the island of the Balize mentioned at p. 446. We need feel no surprise at the quantity of gaseous matter disengaged from cracks in these newly-raised islands, when we recollect that almost everywhere in Europe, where a successful Artesian boring has been made, the water at first spouts up to a height far beyond that to which it would be carried by simple hydrostatic pressure. A portion of the propelling force usually consists of atmospheric air and carbonic acid gas, which last is generated by the decomposition of animal and vegetable matter. Of the latter there must be always a great store in the recent deposits of a delta like that of the Mississippi, as they enclose much drift-timber at all depths, and the pent-up gaseous matter will be ready to escape wherever the overlying impervious clays are upheaved and rent.

Origin of the mud-lumps.—I am informed by Col. Sidell, that when one of the lumps was blown up with gunpowder, a great ebullition of gas, chiefly carburetted hydrogen, took place, and left a crater-shaped hollow. Such gas has also been known to be given out for several years in succession; from which facts the Colonel infers, that when it cannot get vent it may sometimes accumulate to such an amount as to be able to overcome the pressure of the

* Letter to the Author. Oct. 16, 1865.

† American Journ. of Science, vol. xlvii.

incumbent mud, and force it up in the shape of a mud-lump. But this hypothesis leaves unexplained the important fact that the swelling up of the bottom always takes place off what are called 'the passes,' or off the extremity of the delta, near those points where the chief load of fresh sand, gravel, and sediment is thrown down on the muddy bottom of the gulf. The decay of drift timber and other vegetable matter must be going on actively at various depths all over the delta, and often far from the river's mouth; so that it seems to me more probable that the gaseous emanations play only a secondary part, helping to bring up mud from below and deposit it on the slopes of the newly raised mound, as in the eruption of a mud volcano. The initiatory moving power may probably be derived from the downward pressure of the gravel, sand, and sediment accumulated during the flood season off the various mouths or passes, upon a yielding bottom of fine mud and sand. This new deposit, according to Messrs Humphreys and Abbot, forms annually a mass of no less than one mile square, having a thickness of twenty-seven feet. It consists of mud, coarse sand, and gravel, which the river lets fall somewhat abruptly when it first comes in contact with the still salt water of the gulf. A cubic mass of such enormous volume and weight thrown down on a foundation of yielding mud, consisting of materials which, as being very fine and impalpable, had long before been carried out farthest from the land, may well be conceived to exert a downward pressure capable of displacing, squeezing, and forcing up some parts of the adjoining bottom of the gulf, so as to give rise to new shoals and islands.

Railway engineers are familiar with the swelling up of a peat-moss or the bed of a morass, on some adjoining part of which a new embankment has been constructed. I saw an example of this in the year 1839, in the Loch of Rescobie, in Forfarshire, five miles east of the town of Forfar. That lake had been partially drained, and the railway mound was carried over newly-exposed, soft, and swampy ground, which gave way so as to let the mound sink down fifteen feet. It then became necessary to pile up additional matter

fifteen feet thick in order to obtain the required level. On one side of the embankment, the bog, when I visited the place, had swollen up in a ridge 40 feet long and 8 feet high, the upper portion consisting of peaty matter traversed by numerous willow roots. In the highest part of this upraised mass were several irregular cracks about six feet in their greatest width, and open for a depth of two yards or more. On the opposite side of the railway mound, and about 100 yards distant from it, in the middle of what remained of the half-drained loch, a new island or 'mud-lump' was seen, which had begun to rise slowly in 1837, and had attained before 1840 a height of several yards, with a length of about 100 feet, and a width of 25 feet. It was still strewed over with dead fresh-water mussels and other shells; but many land plants had already sprung up, so that its surface was green.

In 1852 I saw a remarkable instance of such a downward and lateral pressure, in the suburbs of Boston (U. S.), near the South Cove. With a view of converting part of an estuary overflowed at high tide into dry land, they had thrown into it a vast load of stone (chiefly granite) and sand, upwards of 900,000 cubic yards in volume. Under this weight the mud had sunk down many yards vertically. Meanwhile the adjoining bottom of the estuary, supporting a dense growth of salt-water plants, only visible at low tide, had been forced gradually upward, in the course of many months, so as to project five or six feet above high-water mark. The upraised mass was bent into five or six parallel anticlinal folds; and below the upper layer of turf, consisting of salt-marsh plants, mud was seen above the level of high tide, full of sea-shells, such as *Mya arenaria*, *Modiola plicatula*, *Sanguinolaria fusca*, *Nassa obsoleta*, *Natica triseriata*, and others. In some of these curved beds the layers of shells were quite vertical. The upraised area was 75 feet wide, and several hundred yards long.

Formations of lakes in Louisiana.—Another striking feature in the basin of the Mississippi, illustrative of the changes now in progress, is the formation by natural causes of great lakes, and the drainage of others. These are especially frequent in

the basin of the Red River in Louisiana, where the largest of them, called the Bistineau, is more than thirty miles long, and has a medium depth of from fifteen to twenty feet. In the deepest parts are seen numerous cypress-trees (*Taxodium distichum*) of all sizes, now dead, and most of them with their tops broken by the wind, yet standing erect under water. This tree resists the action of air and water longer than any other, and, if not submerged throughout the whole year, will retain life for an extraordinary period. Lake Bistineau, as well as Black Lake, Cado Lake, Spanish Lake, Natchitoches Lake, and many others, have been formed, according to Darby, by the gradual elevation of the bed of the Red River, in which the alluvial accumulations have been so great as to raise its channel, and cause its waters, during the flood season, to flow up the mouths of many tributaries, and to convert parts of their courses into lakes. In the autumn, when the level of Red River is again depressed, the waters rush back, and some lakes become grassy meadows, with streams meandering through them.* Thus, there is a periodical flux and reflux between Red River and some of these basins, which are merely reservoirs, alternately emptied and filled, like our tide estuaries—with this difference, that in the one case the land is submerged for several months continuously, and in the other twice in every twenty-four hours. It has happened, in several cases, that a raft of timber or a bar has been thrown by the Red River across some of the openings of these channels, and then the lakes become, like Bistineau, constant repositories of water. But, even in these cases, their level is liable to annual elevation and depression, because the flood of the main river, when at its height, passes over the bar; just as, where sandhills close the entrance of an estuary on the Norfolk or Suffolk coast, the sea, during some high tide or storm, has often breached the barrier and inundated again the interior.

The plains of the Red River and the Arkansas are so low and flat, says Mr. Featherstonhaugh, that, whenever the Mississippi rises thirty feet above its ordinary level, those

* Darby's Louisiana, p. 33.

great tributaries are made to flow back, and inundate a region of vast extent. Both the streams alluded to contain red sediment derived from the decomposition of red porphyry; and since 1833, when there was a great inundation in the Arkansas, an immense swamp has been formed near the Mammelle Mountain, comprising 30,000 acres, with here and there lagoons, where the old bed of the river was situated; in which are seen standing innumerable trees, for the most part dead, of cypress, cotton-wood, or poplar, the triple-thorned acacia, and others of great size. Their trunks appear as if painted red for about fifteen feet from the ground; at which height a perfectly level line extends through the whole forest, marking the rise of the waters during the last flood.*

Messrs. Humphreys and Abbot mention that the upper part of the Red River lies in a gypseous formation containing much red clay, from which, as well as from the porphyry alluded to by Featherstonhaugh, the colour of the sediment may be derived.†

But most probably the causes above assigned for the recent origin of these lakes are not the only ones. Subterranean movements have altered, so lately as the years 1811–12, the relative levels of various parts of the basin of the Mississippi, situated 300 miles north-east of Lake Bistineau. In those years the great valley, from the mouth of the Ohio to that of the St. Francis, including a tract 300 miles in length, and exceeding in area the whole basin of the Thames, was convulsed to such a degree as to create new islands in the river, and lakes in the alluvial plain. Some of these were on the left or east bank of the Mississippi, and were twenty miles in extent; as, for example, those named Reelfoot and Obion in Tennessee, formed in the channels or valleys of small streams bearing the same names.

But the largest area affected by the great convulsion lies eight or ten miles to the westward of the Mississippi, and inland from the town of New Madrid, in Missouri. It is

* Featherstonhaugh, Geol. Report. Washington, 1835, p. 84.

† Report on the Mississippi, p. 40.

called the 'sunk country,' and is said to extend along the course of the White Water and its tributaries, for a distance of between seventy and eighty miles north and south, and thirty miles or more east and west. Throughout this area, innumerable submerged trees, some standing leafless, others prostrate, are seen; and so great is the extent of lake and marsh, that an active trade in the skins of musk-rats, mink, otters, and other wild animals, is now carried on there. In March 1846 I skirted the borders of the 'sunk country' nearest to New Madrid, passing along the Bayou St. John and Little Prairie, where dead trees of various kinds, some erect in the water, others fallen, and strewed in dense masses over the bottom, in the shallows, and near the shore, were conspicuous. I also beheld countless rents in the adjoining dry alluvial plains, caused by the movements of the soil, in 1811–12, still open, though the rains, frost, and river inundations have greatly diminished their original depth. I observed, moreover, numerous circular cavities, called 'sink holes,' from ten to thirty yards wide, and twenty feet or more in depth, which interrupt the general level of the plain. These were formed by the spouting out of large quantities of sand and mud during the earthquakes.*

That the prevailing changes of level in the delta and alluvial plain of the Mississippi have been caused by the subsidence, rather than the upheaval of land, appears to me established by the fact that there are no protuberances of upraised alluvial soil, projecting above the level surface of the great plain. It is true that the gradual elevation of that plain, by new accessions of matter, would tend to efface every inequality derived from this source; but we might certainly have expected to find more broken ground in the great plain westward of the Mississippi, had local upthrows of alluvial strata been of repeated occurrence.

In regard to the strata composing the lower part of the great delta, an observation of Darby deserves attention. In the steep banks of the Atchafalaya, before alluded to, the

* For an account of the 'sunk country,' shaken by the earthquake of 1811–1812, see Lyell's Second Visit to the United States, ch. xxxiii.

following section, says he, is observable at low water:—first an upper stratum, consisting invariably of bluish clay, common to the banks of the Mississippi; below this a stratum of red ochreous earth, peculiar to Red River, under which the blue clay of the Mississippi again appears; and this arrangement is constant, proving, as that geographer remarks, that the waters of the Red River occupied alternately, at some former periods, considerable tracts below their present point of union.* Such alterations are probably common in submarine spaces situated between two converging deltas; for, before the two rivers unite, there must almost always be a certain period when an intermediate tract will by turns be occupied and abandoned by the waters of each stream; since it can rarely happen that the season of highest flood will precisely correspond in each. In the case of the Red River and Mississippi, which carry off the waters from countries placed under widely distant latitudes, an exact coincidence in the time of greatest inundation is very improbable.

Antiquity of the delta and alluvial plain.—After I had examined the pilot station called the Balize, near the mouth of the Mississippi, in 1846, I endeavoured to estimate the quantity of sedimentary matter contained in the delta and in the alluvial plain, and to calculate the minimum of time which the river must have acquired to deposit so vast a mass of matter. The area of the delta was assumed by Mr. Forshey to be about 13,600 square British miles in extent. In the more recent survey of Messrs. Humphreys and Abbot, in 1861, it is taken to be somewhat less, or 12,300 square miles. The average depth of the fluviatile formation in this area I supposed to be somewhat more than 500 feet, and for facility of calculation I assumed it to be 528 feet, or $\frac{1}{10}$ of a mile. My conjectures on this head were founded partly on the depth of the Gulf of Mexico, between the southern point of Florida and the Balize, and partly on borings 600 feet deep, in the delta near Lake Pontchartrain, north of New Orleans, in which the bottom of the alluvial matter was said not to have been reached at that depth—a result confirmed, as we shall

* Darby's Louisiana, p. 103.

presently see by a more recent experiment. For the quantity of sediment contained in the water I adopted Mr. Riddell's estimate of $\frac{1}{1245}$ in weight, and this does not differ materially from the results obtained by Messrs. Humphreys and Abbot after a long series of careful measurements, for they give the solid contents as $\frac{1}{1321}$.

From the data above stated as to the thickness of the delta-deposits and the quantity of solid matter brought down annually by the river (which would amount to 3,702,758,400 cubic feet), I inferred that the accumulation of the whole deposit must have taken 67,000 years. But, in the course of their survey, Messrs. Humphreys and Abbot came to the conclusion that the quantity of water annually discharged by the Mississippi into the gulf had been greatly underrated. They also remarked that the river pushes along the bottom of its channel even to its mouth a certain quantity of sand and gravel, of which I had taken no account, equal, according to them, to about $\frac{1}{10}$ of the mud held in suspension by the river. Allowing, therefore, for this addition and for the larger discharge of muddy water, they make the whole mass of transported matter nearly double that which I had assumed; consequently the number of years required for the growth of the whole delta would be reduced to about one half, or to about 33,500 years, if my former assumed data as to the probable thickness of the deposit be adopted.

But in 1854* another Artesian well was bored at New Orleans to the depth of 630 feet, through strata containing shells of recent species, without any signs of the foundations of the modern deposit having been reached. The mineral character of the strata pierced through, as given in the report of Messrs. Humphreys and Abbot, will be seen to consist throughout of various coloured clays and sands, with much vegetable matter. One bed of sand at the depth of 582 feet is described as nearly stony, but the rest as unconsolidated. At the depth of 66 feet, cypress roots (*Taxodium distichum*) and waterworn pebbles are mentioned—again at 130 feet bark of the cypress occurred, as I learn from Professor Hilgard,

* Report of Survey of Mississippi River, p. 101.

and at the depth of 153 feet a cedar log in a sound state. All these remains are exactly of such a character as we should expect to find in a formation accumulated in the sea off the mouths of the great river.

General Humphreys has had the kindness, at my request, to submit the shells which were brought up from various depths to Professor Hilgard, author of a valuable report on the geology of the State of Mississippi, and he informs me that in one stratum occurring at the depth of 41 feet in the Artesian boring, and which was composed exclusively of shells, he has found 22 pieces of mollusca in a determinable state. All of them are of species now living in the gulf, and of which, with one or two exceptions, he has himself collected specimens on the shores of Ship Island, near the mainland (see map, fig. 38, p. 444). They all belong to salt-water genera, such as Mactra, Arca, Cardium, Lucina, Venus, Pandora, Astarte, Donax, Tellina, Oliva, Marginella, Buccinum, Natica, &c. Recent marine shells occurred at intervals so far down as 235 feet; but among the species obtained at that depth were a Tellina and Cardium which Mr. Hilgard has not yet been able to name. He remarks, however, that they do not agree with any of the American Miocene or Eocene species known to him. From much greater depths, and near the bottom of the boring, shells of living species were again identified, and among them *Venus Paphia*, *Arca transversa*, *A. ponderosa*, and *Gnathodon cuneatus*, the latter bivalve being one which swarms in the lagoons of the delta, such as Lake Pontchartrain, in such numbers that the dead shells are used for making roads. Professor Hilgard compares the upper portions of the deposit pierced through, to a formation called by him 'Coast-Pliocene' (which appears to me of Post-Pliocene age), occurring at slight elevations above the sea along the coast of the gulf in the State of Mississippi (see *a*, *a*, map p. 444). Some beds of this formation he describes as containing the common eatable oyster of America, *O. Virginica*, together with *Mytilus hamatus*, and the living barnacle of that coast, while in other parts it is full of the roots and trunks of the deciduous cypress. As the beds containing these shells are now some feet above the level of the

sea, they bear witness to an upheaval of the bottom of the gulf at a very modern period.

It has already been stated that the base of the marine formation was not reached in the Artesian well at New Orleans at a depth of 630 feet. It will be seen by the map (fig. 38) that at the distance of only twelve miles from the mouth of the South Pass the soundings already give a depth of 95 fathoms. Eight miles farther in the same direction we find 144 fathoms, then at 32 miles 452 fathoms—beyond this 600, and they increase to 1,000 fathoms before we arrive at the Florida Straits. When we consider the manner in which the delta at and below New Orleans protrudes beyond the general coast-line, and that at a distance from the Balize equal to that which separates the Balize from New Orleans, the gulf is 3,000 feet deep, it seems probable that the recent deposit if it could be gauged would prove to be far more than 600 feet thick, and might even attain twice or thrice that thickness. We must be prepared to find that the great bulk of it will contain marine and not fluviatile shells, and that a large part of the whole will consist of fine clay, although here and there pebbles and sand brought down to the bar will have been spread out during storms over wide areas.

In my Second Visit to the United States (vol. ii. p. 154), I have remarked that 'all the pilots agree, that when the Mississippi is at its height, it pours several streams of fresh water, tinged with yellow sediment, for twelve or more miles into the gulf beyond its mouths. These streams, floating over the heavier salt water, spread out into broad superficial sheets or layers, which the keels of vessels plough through, turning up a furrow of clear blue water, which forms a dark streak in the middle of the ship's wake. We may infer, therefore, that both in the summer, when the swollen river is turbid and depositing mud, and in winter, when the sea is making reprisals on the delta, there is a large amount of sediment dispersed far and wide and carried by currents to the deeper and more distant parts of the gulf.'

We learn, from the recent survey of Humphreys and Abbot, that the narrow strip of land formed near the present mouths or passes has been advancing for some time at the rate of

262 feet a year; but this fact supplies us with no data for estimating the rate of growth of the whole delta in past times. On comparing an Admiralty survey map a hundred years old, executed by Captain Gould* between the years 1764 and 1771, with the maps made a hundred years afterwards by the United States surveyors (that by Talcott in 1838, and that of Humphreys and Abbot in 1860), it appears that the land at the South Pass (see map, fig. 38), instead of having advanced has receded about four miles within the last century. This return of the sea to its old limits is doubtless owing to this pass having ceased to be a great channel of discharge, so that, instead of new additions being made to the banks, there has been a loss even of some of the land that had been gained. The denudation in such cases may not extend to a depth of many feet; but it shows, not only how difficult it is to estimate the average rate of advance of the land by observations made during short periods, but how extensively the coarse materials first thrown down on the bars may subsequently be removed and spread out in thin strata over large spaces. Even if we compare the two American surveys already alluded to, of 1838 and 1860, we find that in this interval of twenty-two years a bank of new land in the Pass à l'Outre, measuring two miles east and west by half a mile north and south, had been lost or cut away by the waves.

In boring vertically through any part of the delta, we may expect to pass occasionally through brackish-water strata, formed in lagoons, and through others containing purely marine shells; and if there have been oscillations in the level of the ground, as may well be supposed in the case of tens of thousands of years, there will be alternations of fluviatile beds and fresh-water cypress swamps, with clays and sands containing marine shells. On the whole, I am not disposed to regard the estimate which I made in 1846 of the time required for the accumulation of the delta, as extravagant. The rate at which the river accomplishes a given amount of work is no doubt nearly double what I supposed, as shown

* Admiral Richards, of the Hydrographical Office, had the kindness to show me the original of this map.

by Messrs. Humphreys and Abbot; but, on the other hand, the quantity of work done, or of mud and sand which has been carried down into the gulf, is far greater than that which I assumed as the basis of my calculation.

We have no information obtained by borings in regard to the thickness of the alluvial deposit in the plain above the delta, the superficial area of which is about equal to that of the delta itself. I assumed it to average half that of the delta, or 264 feet. I grounded this conclusion partly on the idea that the valley had been subsiding, as a part of it sank during the earthquake of New Madrid in 1811-12, and partly on the fact that the Mississippi is continually shifting its course in the great alluvial plain, cutting its channel to the depth of 100 feet, and sometimes even to 250 feet,—filling up on one side as much space as it scoops out on the other; and these changes alone must, I think, have given a considerable depth to the alluvial deposit, independently of the filling up of the original basin of the great river, the capacity of which was probably increased by repeated subsidences.

If we ascend the Mississippi for 165 miles above New Orleans, we find at Port Hudson, on the east or left bank of the river, a cliff continually undermined by the stream. This cliff I examined in 1846, and the state of it had been well described sixty-nine years before by Bartram the botanist. At the base of it, about forty feet above the level of the gulf, is a buried forest, with the stools and roots in their natural position, and composed of such trees as now live in the swamps of the delta and alluvial plain, the deciduous cypress being the most conspicuous of them. Above this buried forest the bluff rises to a height of about 75 feet, and it affords a section of beds of river-sand, including trunks of trees and pieces of drift-wood, and above the sand a brown clay. From the top of the cliff the ground slopes to a height of 150 feet above the level of the buried forest, or about 200 feet above the sea. From this section we learn that there have been great movements and oscillations of level since the Mississippi began to form an alluvial plain, and to drift down timber into it, and to bury under its sand and sediment ancient forests, resembling those which now flourish in the swamps of its

plain and delta. When the trees were buried, the ground was probably sinking, after which it must have been raised again, so as to allow the stream to cut through its old alluvium. The depth of this ancient fluviatile formation is seen to be no less than 200 feet, without any signs of the bottom being reached. In character it is identical with the deposit called Coast-Pliocene by Prof. Hilgard (see p. 456, and *a*, *a*, map, p. 444), of which, I presume, it is a continuation, but no marine shells have been detected in Hudson's Bluff, like those occasionally met with on the coast.

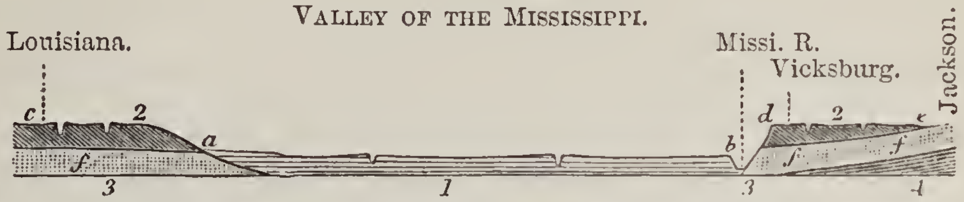
If, again, we ascend the river to about sixty-five miles due north of Port Hudson, or about 225 above New Orleans, we observe another bluff at Natchez, on the same left bank of the river, more than 200 feet in perpendicular height. The lower part of this cliff consists of gravel and sand, while the uppermost, sixty feet in thickness, is a mass of loam exactly resembling the loess of the valley of the Rhine, without stratification, and full of land-shells, such as Helix and Pupa, together with the amphibious genus Succineæ, all of species now living in the same country. At a few points in the lower part of this formation, I observed shells of living species of Lymnea, Planorbis, and Cyclas, genera which inhabit ponds, and which may indicate the channel of an ancient river, on the borders of which, after it had shifted its course, the loess was deposited during inundations. This same loess is continuous over a vast extent of country, always increasing in thickness near the Mississippi. It occurs in a bluff at Vicksburg, eighty miles due north of Natchez (see section, fig. 42), where it forms a broad, flat table-land, extending inland about twenty-six miles from the Mississippi, or eastward from *d* to *e*. It also recurs, as I learnt from Mr. Forshey, to the west of the valley of the Mississippi, in Louisiana, or at *c*, fig. 42.

The only fossils of a truly fluviatile character which have been met with anywhere in this loess are the remains of three fish discovered lately (March 19, 1866,) by Colonel Green. They were found in the great platform of loess, two miles north of Vicksburg, and only four feet below the surface, at the height of 200 feet above high-water mark. They are

considered by Dr. Leidy to belong to the living buffalo-fish of the Mississippi, and they probably indicate some local and exceptional conditions, connected with a more rapid accumu-

Fig. 42.

Valley of the Mississippi.



1. Modern alluvium of Mississippi. 2. Loam or Loess. 3. *f*. Eocene. 4. Cretaceous.

lation than usual of mud on a part of the inundated plain on which no organic remains were usually preserved except land-shells and Succineæ. I consider the loess, from its homogeneous nature, the absence of stratification, and its terrestrial and amphibious shells, to have been formed by a great river which, like the Nile, inundated the wide plains bordering it on each side. Granting this, we must assume that since its accumulation there have been great changes in the level of the basin of the Mississippi. How far the loess may have been anterior to all the formations pierced through in the well at New Orleans, or whether it may have been contemporaneous with some of them, is a point I cannot pretend to decide, especially as the Port Hudson formation bears testimony to oscillations of level at a very modern period. But it is evident that the basin of the great river has undergone important changes since the loess was deposited, although the species of land-shells contained therein are all now living. As to the mammalia, of which some bones have been found in the lowest part of the loess and in clay at its base, they are many of them of extinct species. Among these are *Mastodon giganteus*, a species of *Megalonyx*, a *Mylodon*, *Bison latifrons*, *Equus Americanus*, *Felis atrox* Leidy (a large carnivore of the size of the tiger), two species of deer, two of bear and other quadrupeds, some extinct and others still living.

Before we take leave of the great delta we may derive an instructive lesson from the reflection that the new deposits already formed, or now accumulating, whether marine or fresh-water, greatly resemble in composition, and in the general character of their organic remains, many ancient

strata which enter largely into the structure of the earth's crust. Yet there is no sudden revolution in progress, whether on the land or in the waters, whether in the animate or the inanimate world. Notwithstanding the excessive destruction of soil and uprooting of trees, the region, which yields a never-failing supply of drift-wood, is densely clothed with noble forests, and is almost unrivalled in its power of supporting animal and vegetable life. In spite of the undermining of many a lofty bluff and the encroachments of the delta on the sea—in spite of the earthquake, which rends and fissures the soil, or causes areas more than sixty miles in length to sink down several yards in a few months—the general features of the district remain unaltered, or are merely undergoing a slow and insensible change. Herds of wild deer graze on the pastures, or browse upon the trees; and, if they diminish in number, it is only where they give way to man and the domestic animals which follow in his train. The bear, the wolf, the fox, the panther, and the wild cat still maintain themselves in the fastnesses of the forests of cypress and gum-tree. The racoon and the opossum are everywhere abundant; while the musk-rat, otter, and mink still frequent the rivers and lakes, and a few beavers and buffaloes have not yet been driven from their ancient haunts. The waters teem with alligators, tortoises, and fish, and their surface is covered with millions of migratory waterfowl, which perform their annual voyage between the Canadian lakes and the shores of the Mexican Gulf. The power of man, it is true, begins almost everywhere to be sensibly felt, and many parts of the wilderness to be replaced by towns, orchards, and gardens. The gilded steamboats, like moving palaces, stem the force of the current, or shoot rapidly down the descending stream through the solitudes of the forests and prairies. Already does the flourishing population of the great valley far exceed that of the thirteen United States when first they declared their independence. Such is the state of a continent where trees and stones are hurried annually, by a thousand torrents, from the mountains to the plains, and where sand and finer matter are swept down by a vast current to the sea, together with the wreck of countless forests and the bones of animals

which perish in the inundations. When these materials reach the gulf, they do not render the waters unfit for aquatic animals; but, on the contrary, the sea here swarms with life, as it generally does where the influx of a great river furnishes a copious supply of organic and mineral matter. Yet some people, when they behold the spoils of the land heaped in successive strata, and blended confusedly with the remains of fishes, broken shells, and corals—when they see portions of erect trunks of trees with their roots still retaining their natural position, and one tier of them preserved above another—are apt to imagine that they are viewing the signs of a turbulent instead of a tranquil and settled state of the planet. They read in such phenomena the proof of chaotic disorder and reiterated catastrophes, instead of indications of a surface as habitable as the most delicious and fertile districts now tenanted by man.

Delta of the Amazons.—What has generally been called the delta of the Amazons forms, according to Mr. Bates,* an irregular triangle, of which each side measures about 180 miles; but the island of Marajo, which is as large as Sicily, occupies a great portion of this space, and inside of this to the west there are other smaller islands, all now, like Marajo, surrounded by different arms of the Amazons, and of the Para, the waters of which are blended in a common estuary. The valley of the Amazons has been lately examined by Professor Agassiz, who describes it as consisting of three formations, all of which he considers to be of Post-tertiary date, and to have been deposited in succession far and wide in the great basin.† The lowest is a sandstone; the next above consists of mottled plastic clays, overlaid by a series of finely laminated clays of various colours, and containing well-preserved leaves of plants supposed to belong to the existing vegetation of the country. These clays pass upwards into sands and sandstone, occasionally divided by an argillaceous layer, and at some points, as at Obydos, on the mainland, nearly 300 miles westward of Marajo, calcareous beds occur with fresh-water bivalve shells of existing species. Over this

* Henry Walter Bates, Delta of the Amazons, Brit. Assoc. Report, 1864, p. 137.

† Agassiz, Physical History of Valley of Amazons, Atlantic Monthly, vol. xviii. July and August 1866.

occurs the third deposit, which appears to me, from the description given of it by Agassiz, to resemble in some parts inundation-mud or loess, and in others the produce of land-floods, which, after denuding the subjacent sandstone, have left masses of unstratified materials to level up the uneven surface of the denuded strata. The above-mentioned formations have been traced, according to Agassiz, over an area 3,000 miles in length and 700 in breadth, and their united thickness exceeds 800 feet. By the earlier observers the stratified portions of this series were supposed to be of marine origin, and were successively referred to the Devonian, Triassic, and Tertiary epochs; but Agassiz inferred that they were of modern date, and, wherever he had opportunities of examining them, of fresh-water origin. The Obydos fossils above alluded to, which former travellers ascribed to the genera Avicula, Solen, and Arca, are in reality, according to Agassiz, Unios or fresh-water bivalves of the family of Naiades, greatly resembling in shape the marine genera above mentioned, but of species now living in the Amazons. Mr. Bates informs me that Spix and Martius considered certain calcareous beds of the same formation, which occur nearer the sea and are used for making lime, to be of marine origin. These shell-beds are found at the mouth of the Tocantins, on the island of Marajo, and towards the sea-coast near Vigia. From the latter place Mr. Bates himself procured large marine univalves of existing species, some of them allied to Fusus.

More lately (October 1870) Professor James Orton, of Vassor College, New York, found shells indicating fresh or brackish water life in the coloured plastic clays at Pabos, more than 2,000 miles up the river, which he considers to be the equivalent of the mottled plastic clays of Agassiz. Mr. Conrad, to whom these shells were submitted, states that most of the forms are very singular and unique, belonging to about seventeen extinct species, referable to nine genera, of which only three are now living. From this it is inferred, says Professor Orton, that the formation cannot be late Tertiary, and may be Miocene.* The great mass of shells are bivalves

* See H. Woodward on Tertiary Shells of the Amazons Valley, Ann. and Mag. of Nat. Hist., Jan. and Feb. 1871; and Conrad, American Journ. of Conchology, Oct. 10, 1870.

of Conrad's new genus *Anysothyris* (*Pachydon Gabb*), now represented in the estuary of the La Plata by *Potomomya* (*Azara*) *labiata*. Assuming that the seventeen species are all extinct, this would imply that this fossil fauna recedes more from that now living than does any known member even of the Lower Miocene of Europe.

That we should be unable to form even a probable guess as to the geological and geographical relations of these deposits, in a country which has only been surveyed in what must be called a rapid and hurried visit during a single season, is not wonderful. Suppose, for example, that a scientific expedition had explored for the first time the valley of the Rhine. On entering the Scheldt they would find at Antwerp Pliocene strata, in some of which the great majority of shells agree with those now living in the neighbouring sea. Pursuing their course up the river for 200 or 300 miles, they would behold on both sides of the valley of the Rhine, as between Bingen and Basle, a mass of loess, with recent land and amphibious shells, from 100 to 200 feet thick, having sometimes, but rarely, at the bottom, fresh-water deposits, with living species of Lymnea, Planorbis, and Paludina comparable in age to those of Obydos; while at Bonn, Mayence, and other places they would find Tertiary strata containing at various heights fresh-water, brackish, and marine fossils, for the most part of extinct species and Miocene date. In the report of such a supposed expedition made for the first time it would be unreasonable to expect that the successive changes in organic life or physical geography of the Tertiary and recent formations of the Rhenish basin should be clearly determined, seeing that after the study of more than half a century we have not yet accomplished this end. Yet the basin of the Rhine is only a fourth part the size of that of the Amazons.

In order to explain the great Amazonian formation above described, Professor Agassiz conceives that the whole valley was for a long period converted into a lake, by a large dam or barrier stretching across its seaward extremity, and which has since been removed by the ocean. A similar hypothesis has been advanced again and again to account for the vast extent of old fluviatile and lacustrine deposits, as well as

for the inundation-mud called loess, which once filled the lower portions of the basins of most of the principal rivers of the world, such as the Mississippi, Nile, Danube, and Rhine. I have elsewhere* endeavoured to show that such phenomena are the natural result of oscillations in the level of the land, extending over large continental areas, by which the fall of the rivers is lessened at certain periods, giving rise to accumulations of matter more or less lacustrine, while subsequently, when a movement takes place in an opposite direction, the rivers cut through their old deposits, re-excavating the valleys and often eroding them below their original depth. There is nothing new, therefore, in the character of the Amazonian clays, sands, and loess, so far at least as they are of recent and post-Tertiary date, except the grand scale on which they are developed. Geologists have usually been driven to abandon the theory of a seaward dam at the mouths of great rivers, such as the Rhine and Mississippi, by the difficulty of imagining first the construction of such barriers after the valley was formed, and then their subsequent disappearance.

Professor Agassiz has hazarded the startling conjecture that the Amazonian basin was closed up and converted into a lake by the terminal moraine of a glacier, which stretched for thousands of miles from west to east, and entered the sea under the equator. But this distinguished naturalist candidly confesses that he failed to discover any of those proofs which we are accustomed to regard, even in temperate latitudes, as essential for the establishment of the former existence of glaciers where they are now no more. No glaciated pebbles, or far-transported angular blocks, with polished and striated sides, no extensive surface of rock, smooth and traversed by rectilinear furrows, were observed.

The islands, such as Marajo and others, off the present mouth of the Amazons, certainly imply that vast encroachments of the ocean have taken place since the clays and sands above described were formed. We are also informed by Agassiz that even in the last ten years the sea has gained upon the land on one part of the coast as much as 200 yards,

* See above, p. 301, and Ant. of Man, p. 333; Elements of Geology, p. 118.

and within the last twenty years one island north-east of the Bay of Vigia has been entirely swept away, while it is probable that the Paranahyba and some other rivers in the province of Maranham, which now enter the ocean by independent mouths, were once tributaries of the Amazons. From Mr. Bates we learn that, about 140 miles inland from the present coast-line, is a low flat area about 80 miles in length and width, wholly formed of mud and sediment in comparatively recent times, by the Amazons. The same traveller gives us a graphic account of the rate at which the great river in the higher parts of its course is denuding its banks. 'One morning,' he says, 'I was awoke before sunrise by an unusual sound resembling the roar of artillery; the noise came from a considerable distance, one crash succeeding another. I supposed it to be an earthquake, for, although the night was breathlessly calm, the broad river was much agitated, and the vessel rolled heavily. Soon afterwards another loud explosion took place, followed by others, which lasted for an hour till the day dawned, and we then saw the work of destruction going forward on the other side of the river, about three miles off. Large masses of forest, including trees of colossal size, probably 200 feet in height, were rocking to and fro, and falling headlong one after another into the water. After each avalanche, the wave which it caused returned on the crumbly bank with tremendous force, and caused the fall of other masses by undermining. The line of coast over which the landslip extended was a mile or two in length; the end of it, however, was hid from our view by an intervening island. It was a grand sight; each downfall created a cloud of spray; the concussion in one place causing other masses to give way a long distance from it, and thus the crashes continued, swaying to and fro with little prospect of a termination. When we glided out of sight two hours after sunrise the destruction was still going on.' *

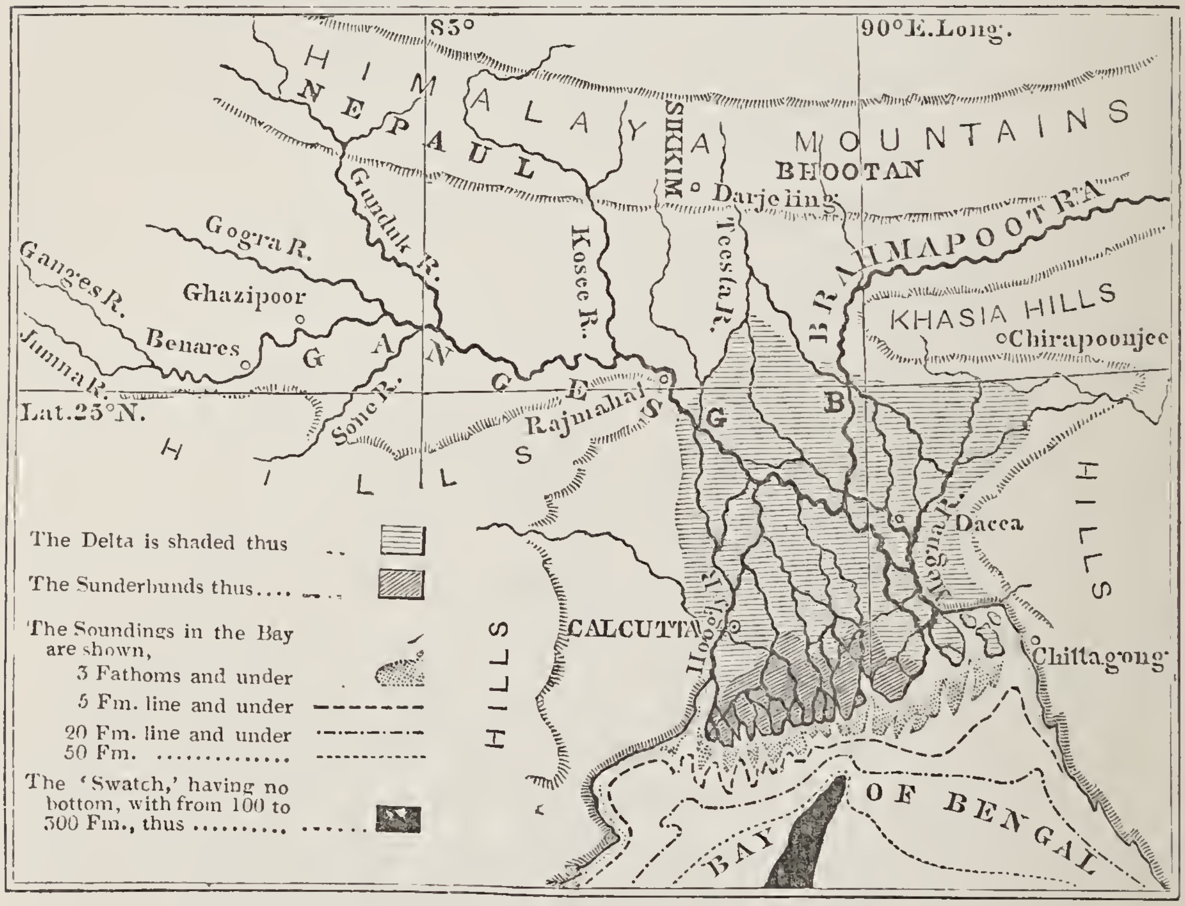
DELTA OF THE GANGES AND BRAHMAPOOTRA.

As an example of a large delta advancing upon the sea in spite of the action of a very powerful tide, I shall next

* Bates, Naturalist on the Amazons, vol. ii. p. 172. 1863.

describe that of the Ganges and Brahmapootra (or Burrampooter). These, the two principal rivers of India, descend from the highest mountains in the world, and partially mingle their waters in the low plains of Hindoostan, before reaching the head of the Bay of Bengal. The Brahmapootra, somewhat the larger of the two, formerly passed to the east of Dacca, even so lately as the beginning of the present century, pouring most of its waters into one of the numerous channels in the delta called 'the Megna.' By that name the main stream was always spoken of by Rennell and others in their

Fig. 43.



Map of the Delta of the Ganges and Brahmapootra.

memoirs on this region. But the main trunk now unites with an arm of the Ganges considerably higher up, at a point about 100 miles distant from the sea; and it is constantly, according to Dr. Hooker, working its way westward, having formerly, as may be seen by ancient maps, moved eastward for a long period.

The area of the delta of the combined rivers—for it is impossible now to distinguish what belongs to each—is considerably more than double that of the Nile, even if we exclude

from the delta a large extent of low, flat, alluvial plain, doubtless of fluviatile origin, which stretches more than 100 miles to the hills west of Calcutta (see map, fig. 43,) and much farther in a northerly direction beyond the head of the great delta. The head of a delta, as before stated, is that point where the first arm is given off. Above that point a river receives the waters of tributaries flowing from higher levels; below it, on the contrary, it gives out portions of its waters to lower levels through channels which flow into adjoining swamps, or which run directly to the sea. In the great delta of Bengal there may be said to be two heads nearly equi-distant from the sea, that of the Ganges (G, map, fig. 43), about thirty miles below Rajmahal, or 216 statute miles in a direct line from the sea, and that of the Brahmapootra (B) below Chirapoonjee, where the river issues from the Khasia mountains, a distance of 224 miles from the Bay of Bengal.

It will appear, by reference to the map, that the great body of fresh water derived from the two rivers enters the bay on its eastern side; and that a large part of the delta bordering on the sea is composed of a labyrinth of rivers and creeks, all filled with salt water, except those immediately communicating with the Hoogly, or principal arm of the Ganges. This tract alone, known by the name of the Woods, or Sunderbunds (more properly Soonderbuns), a wilderness infested by tigers and crocodiles, is, according to Rennell, equal in extent to the whole principality of Wales.*

On the sea-coast there are eight great openings, each of which has evidently, at some ancient period, served in its turn as the principal channel of discharge. Although the flux and reflux of the tide extend even to the heads of the delta when the rivers are low, yet, when they are periodically swollen by tropical rains, their volume and velocity counteract the tidal current, so that, except very near the sea, the ebb and flow become insensible. During the flood season, therefore, the Ganges and Brahmapootra almost assume in their delta the character of rivers entering an inland sea; the movements of the ocean being then subordinate to the

* Account of the Ganges and Burrampooter Rivers, by Major Rennell, Phil. Trans. 1718.

force of the rivers, and only slightly disturbing their operations. The great gain of the delta in height and area takes place during the inundations; and, during other seasons of the year, the ocean makes reprisals, scouring out the channels, and sometimes devouring rich alluvial plains.

Islands formed and destroyed.—Major R. H. Colebrooke, in his account of the course of the Ganges, relates examples of the rapid filling up of some of its branches, and the excavation of new channels where the number of square miles of soil removed in a short time (the column of earth being 114 feet high) was truly astonishing. Forty square miles, or 25,600 acres, are mentioned as having been carried away, in one place, in the course of a few years.* The immense transportation of earthy matter by the Ganges and Brahmapootra is proved by the great magnitude of the islands formed in their channels during a period far short of that of a man's life. Some of these, many miles in extent, have originated in large sand-banks thrown up round the points at the angular turning of the rivers, and afterwards insulated by breaches of the streams. Others, formed in the main channel, are caused by some obstruction at the bottom. A large tree, or a sunken boat, is sometimes sufficient to check the current and cause a deposit of sand, which accumulates till it usurps a considerable portion of the channel. The river then undermines its banks on each side, to supply the deficiency in its bed, and the island is afterwards raised by fresh deposits during every flood. In the great gulf below Luckipour, formed by the united waters of the Ganges and Megna, some of the islands, says Rennell, rival in size and fertility the Isle of Wight. While the river is forming new islands in one part, it is sweeping away old ones in others. Those newly formed are soon overrun with reeds, long grass, the Tamarix Indica, and other shrubs, forming impenetrable thickets, where the tiger, the rhinoceros, the buffalo, deer, and other wild animals, take shelter. It is easy, therefore, to perceive, that both animal and vegetable remains may occasionally be precipitated into the flood, and become imbedded in the sediment which subsides in the delta.

* Trans. of the Asiatic Society, vol. vii. p. 14.

Three or four species of crocodile, of two distinct sub-genera, abound in the Ganges, and its tributary and contiguous waters; and Mr. H. T. Colebrooke informed me, that he had seen both forms in places far inland, several hundred miles from the sea. The Gangetic crocodile, or Gavial (in correct orthography, Garial), is confined to the fresh water, living exclusively on fish; but the commoner kinds, called Koomiah and Muggar, frequent both fresh and salt, being much larger and fiercer in salt and brackish water.* These animals swarm in the brackish water along the line of sand-banks, where the advance of the delta is most rapid. Hundreds of them are seen together in the creeks of the delta, or basking in the sun on the shoals without. They will attack men and cattle, destroying the natives when bathing, and tame and wild animals which come to drink. 'I have not unfrequently,' says Mr. Colebrooke, 'been witness to the horrid spectacle of a floating corpse seized by a crocodile with such avidity that he half emerged above the water with his prey in his mouth.' The geologist will not fail to observe how peculiarly the habits and distribution of these saurians expose them to become imbedded in the horizontal strata of fine mud which are annually deposited over many hundred square miles in the Bay of Bengal. The inhabitants of the land who happen to be drowned or thrown into the water are usually devoured by these voracious reptiles; but we may suppose the remains of the saurians themselves to be continually entombed in the new formations. The number, also, of bodies of the poorer class of Hindoos thrown annually into the Ganges is so great, that some of their bones or skeletons can hardly fail to be occasionally enveloped in fluviatile mud.

It sometimes happens, at the season when the periodical flood is at its height, that a strong gale of wind, conspiring with a high spring-tide, checks the descending current of the

* Cuvier referred the true crocodiles of the Ganges to a single species, *C. biporcatus*. But I learn from Dr. Falconer that there are three well-marked species, *C. biporcatus*, *C. palustris*, and *C. bombifrons*. *C. bombifrons* occurs in the northern branches of the Ganges, 1,000 miles from Calcutta; *C. biporcatus* appears to be confined to the estuary; and *C. palustris*, to range from the estuary to the central parts of Bengal. The Garial (*C. palustris*) is found along with *C. bombifrons* in the north, and descends to the region of *C. biporcatus* in the estuary.

river, and gives rise to most destructive inundations. From this cause, in the year 1763, the waters at Luckipour rose six feet above their ordinary level, and the inhabitants of a considerable district, with their houses and cattle, were totally swept away.

The population of all oceanic deltas are particularly exposed to suffer by such catastrophes, recurring at considerable intervals of time; and we may safely assume that such tragical events have happened again and again, since the Gangetic delta was inhabited by man. If human experience and forethought cannot always guard against these calamities, still less can the inferior animals avoid them; and the monuments of such disastrous inundations must be looked for in great abundance in strata of all ages, if the surface of our planet has always been governed by the same laws. When we reflect on the general order and tranquillity that reign in the rich and populous delta of Bengal, notwithstanding the havoc occasionally committed by the depredations of the ocean, we perceive how unnecessary it is to attribute the imbedding of successive races of animals in older strata to extraordinary energy in the causes of decay and reproduction in the infancy of our planet, or to those general catastrophes and sudden revolutions so often resorted to.

Deposits in the delta.—The quantity of mud held in suspension by the waters of the Ganges and Brahmapootra is found, as might be expected, to exceed that of any of the rivers alluded to in this or the preceding chapters; for, in the first place, their feeders flow from mountains of unrivalled altitude, and do not clear themselves in any lake, as does the Rhine in the Lake of Constance, or the Rhone in that of Geneva. And, secondly, their whole course is nearer the equator than that of the Mississippi, or any great river respecting which careful experiments have been made, to determine the quantity of its water and earthy contents. The fall of rain, moreover, as we have before seen, is excessive on the southern flanks of the first range of mountains which rise from the plains of Hindoostan, and still more remarkable is the quantity sometimes poured down in one day. (See above, p. 324.) The sea, where the Ganges and Brahmapootra

discharge their main stream at the flood season, only recovers its transparency at the distance of from 60 to 100 miles from the delta; and we may take for granted that the current continues to transport the finer particles much farther south than where the surface water first becomes clear. The general slope, therefore, of the new strata must be extremely gentle. According to the best charts, there is a gradual deepening from four to about sixty fathoms, as we proceed from the base of the delta to the distance of about one hundred miles into the Bay of Bengal. At some few points seventy, or even one hundred, fathoms are obtained at that distance.

One remarkable exception, however, occurs to the regularity of the shape of the bottom. Opposite the middle of the delta, at the distance of thirty or forty miles from the coast, there is a deep submarine valley, called the 'swatch of no ground,' about fifteen miles in breadth, where soundings varying from 180 to 300 fathoms fail to reach the bottom. (See map, p. 468.) This phenomenon is the more extraordinary, since the depression runs north to within five miles of the line of shoals; and not only do the waters charged with sediment pass over it continually, but, during the monsoons, the sea, loaded with mud and sand, is beaten back in that direction towards the delta. As the mud is known to extend for eighty miles farther into the gulf, a considerable thickness of matter must have been deposited in 'the swatch.' We may conclude, therefore, either that the original depth of this part of the Bay of Bengal was excessive, or that subsidences have occurred in modern times. The latter conjecture is the less improbable, as the delta near Calcutta has certainly been sinking (as shown by Artesian borings, see p. 476) during the period of its formation. Parts of Bengal have also been convulsed in the historical era by earthquakes, and actual subsidences have taken place in the neighbouring coast of Chittagong, while 'the swatch' lies not far from the volcanic band which connects Sumatra, Barren Island, and Ramree.*

Mr. Fergusson has suggested that 'the swatch,' in which

* See below, Chaps. XXIII. and XXX.

soundings have been made to the depth of no less than 1,800 feet without reaching the bottom, is a channel 'scooped out' by the force of the tides, or one which they have had power to keep clear. In support of this view he observes that the tides of the Hoogly have a rotatory motion; * but he is unable to confirm this by any exact observations as to their velocity, such as might warrant us in ascribing so extraordinary an effect to their excavating power. To me it seems less difficult to conceive the pre-existence of a submarine valley 2,000 feet or more deep, which may have formed part of the original basin of the Bay of Bengal. Before the two great rivers the Ganges and Brahmapootra reach this deep and central part of the gulf they meet the tidal current, and, their speed being checked, they part with their sediment, which has in this way been prevented from filling up 'the swatch.'

Opposite the mouth of the Hoogly River, and immediately south of Saugor Island, four miles from the nearest land of the delta, a new islet was formed at the beginning of the present century, called Edmonstone Island, on the centre of which a beacon was erected as a landmark in 1817. In 1818 the island had become two miles long and half a mile broad, and was covered with vegetation and shrubs. Some houses were then built upon it, and in 1820 it was used as a pilot station. The severe gale of 1823 divided it into two parts, and so reduced its size as to leave the beacon standing out in the sea, where, after remaining seven years, it was washed away. The islet in 1836 had been converted by successive storms into a sand-bank, half a mile long, on which a sea-mark was placed.

Although there is evidence of gain at some points, the general progress of the coast is very slow; for the tides, when the river water is low, are actively employed in removing alluvial matter. In the Sunderbunds the usual rise and fall of the tides is no more than eight feet, but, on the east side of the delta, Dr. Hooker observed, in the winter of 1851, a rise of from sixty to eighty feet, producing among the islands at the mouths of the Megna and Fenny Rivers a lofty

* Fergusson, Changes in Delta of the Ganges, Quart. Geol. Journ. vol. xix. 1863.

wave or 'bore' as they ascend, and causing the river water to be ponded back, and then to sweep down with great violence when the tide ebbs. The bay for forty miles south of Chittagong is so fresh that neither algæ nor mangroves will grow on it. We may, therefore, conceive how effective may be the current formed by so great a volume of water in dispersing fine mud over a wide area. Its power is sometimes augmented by the agitation of the bay during hurricanes in the month of May. The new superficial strata consist entirely of fine sand and mud; such, at least, are the only materials which are exposed to view in regular beds on the banks of the numerous creeks. Neither here nor higher up the Ganges could Dr. Hooker discover any land or fresh-water shells in sections of the banks, which in the plains higher up sometimes form cliffs, eighty feet in height, at low water. In like manner I have elsewhere stated* that I was unable to find any buried shells in the delta or modern river cliffs of the Mississippi.

The Ganges is always raising the level of its bed and banks in the same manner as the Mississippi, before described (p. 439, diagram, fig. 37); and we learn from Sir Proby Cautley and Colonel Baker, that even artificial canals constructed for inland navigation in India, such as those of the Jumna, through which the water flows freely, deposit in like manner much of the coarser matter immediately on their banks, so that these last form a miniature representation of those of larger rivers. Mr. J. Fergusson, in his paper on the Delta of the Ganges,† differing from all writers of authority who preceded him, has argued that the sediment is thrown down in consequence of the overflowing river being checked by meeting with the still water of the jheels or lakes corresponding to those seen at *g f* and *d e*, fig. 37, p. 439. In point of fact, however, the deposition of the coarser matter takes place immediately on the highest part of the banks, where the waters first begin to overflow, and before they reach those lakes which occur at a lower level in the alluvial plain on each side of the main river. The banks are of equal height and as continuous where no jheels exist.

* Second Visit to United States, vol. ii. p. 145.

† Fergusson, ibid.

No substance so coarse as gravel occurs in any part of the delta of the Ganges and Brahmapootra, nor nearer the sea than 400 miles. Yet it is remarkable that the boring of an Artesian well at Fort William, near Calcutta, in the years 1835–40, displayed, at the depth of 120 feet, clay and sand with pebbles. This boring was carried to a depth of 481 feet below the level of Calcutta, and the geological section obtained in the operation has been recorded with great care. Under the surface soil, at a depth of about ten feet, they came to a stiff blue clay about forty feet in thickness; below which was sandy clay, containing in its lower portion abundance of decayed vegetable matter, which at the bottom assumed the character of a stratum of black peat two feet thick. This peaty mass was considered as a clear indication (like the 'dirt-bed' of Portland) of an ancient terrestrial surface, with a forest or Sunderbund vegetation. Logs and branches of a red-coloured wood occur both above and immediately below the peat, so little altered that Dr. Wallich was able to identify them with the Soondri tree, *Heritiera littoralis*, one of the most prevalent forms at the base of the delta. Dr. Falconer tells me that similar peat has been met with at other points round Calcutta at the depth of nine feet and twenty-five feet. It appears, therefore, that there has been a sinking down of what was originally land in this region, to the amount of seventy feet or more; for Calcutta is only a few feet above the level of the sea, and the successive peat-beds seem to imply that the subsidence of the ground was gradual or interrupted by several pauses. Continuing the boring at Fort William, they entered, below the vegetable mass, upon a stratum of yellowish clay about ten feet thick, containing horizontal layers of kunkar (or kankar), a nodula, concretionary, argillaceous limestone, met with abundantly at greater or less depths in all parts of the valley of the Ganges, over many thousand square miles, and always presenting the same characters, even at a distance of one thousand miles north of Calcutta. Some of this kunkar is said to be of very recent origin in deposits formed by river inundations near Saharanpoor. After penetrating 120 feet, they found loam

containing water-worn fragments of mica-slate and other kinds of rock, of a size which the current of the Ganges can no longer transport to this region. In the various beds pierced through below, consisting of clay, marl, and friable sandstone, with kunkar here and there intermixed, no organic remains of decidedly marine origin were met with. Too positive a conclusion ought not, it is true, to be drawn from such a fact, when we consider the narrow bore of the auger and its effect in crushing shells and bones. Nevertheless, it is worthy of remark, that the only fossils obtained in a recognisable state were of a fluviatile or terrestrial character. Thus, at the depth of 350 feet, the bony shell of a tortoise, or trionyx, a fresh-water genus resembling the living species of Bengal, was found in sand. From the same stratum, also, they drew up the lower half of the humerus of a ruminant, of the size and shape, says Dr. Falconer, of the shoulder-bone of the *Cervus porcinus*, or common hog-deer, of India. At the depth of 380 feet, clay with fragments of lacustrine shells was incumbent on what appears clearly to have been another 'dirt-bed,' or stratum of decayed wood, implying a period of repose of some duration, and a forest-covered land, which must have subsided 300 feet, to admit of the subsequent superposition of the overlying deposits. It has been conjectured that, at the time when this area supported trees, the land extended much farther out into the Bay of Bengal than now, and that in later times the Ganges, while enlarging its delta, has been only recovering lost ground from the sea.

At the depth of about 400 feet below the surface, an abrupt change was observed in the character of the strata, which were composed in great part of sand, shingle, and boulders, the only fossils observed being the vertebræ of a crocodile, shell of a trionyx, and fragments of wood very little altered and similar to that buried in beds far above. These gravelly beds constituted the bottom of the section at the depth of 481 feet, when the operations were discontinued in consequence of an accident which happened to the auger.

The occurrence of pebbles at the depths of 120 and 400 feet

implies important changes in the geographical condition of the region round or near Calcutta. The fall of the river, or the general slope of the alluvial plain, may have been formerly greater; or, before a general and perhaps unequal subsidence, hills once nearer the present base of the delta may have risen several hundred feet, forming islands in the bay, which may have sunk gradually, and become buried under fluviatile sediment.

Antiquity of the delta.—It would be a matter of no small scientific interest, if experiments were made to enable us to determine, with some degree of accuracy, the mean quantity of earthy matter discharged annually into the sea by the united waters of the Ganges and Brahmapootra. The Rev. Mr. Everest instituted, in 1831–2, a series of observations on the earthy matter brought down by the Ganges, at Ghazepoor, 500 miles from the sea. He found that, in 1831, the number of cubic feet of water discharged by the river per second at that place was during the

Rains (4 months)	494,208
Winter (5 months)	71,200
Hot weather (3 months) . . .	36,330

so that we may state in round numbers that 500,000 cubic feet per second flow down during the four months of the flood season, from June to September, and about 60,000 per second during the remaining eight months.

The average quantity of solid matter suspended in the water during the rains was, by weight, $\frac{1}{428}$th part; but as the water is about one half the specific gravity of the dried mud, the solid matter discharged is $\frac{1}{856}$th part in bulk, or 577 cubic feet per second. This gives a total of 6,082,041,600 cubic feet for the discharge in the 122 days of the rain. The proportion of sediment in the waters at other seasons was comparatively insignificant, the total amount during the five winter months being only 247,881,600 cubic feet, and during the three months of hot weather, 38,154,240 cubic feet. The total annual discharge, then, would be 6,368,077,440 cubic feet.

This quantity of mud would in one year raise a surface of 228½ square miles, or a square space, each side of which should measure 15 miles, a height of one foot. To give some idea of the magnitude of this result, we will assume that the specific gravity of the dried mud is only one half that of granite (it would, however, be more): in that case, the earthy matter discharged in a year would equal 3,184,038,720 cubic feet of granite. Now about 12½ cubic feet of granite weigh one ton; and it is computed that the Great Pyramid of Egypt, if it were a solid mass of granite, would weigh about 6,000,000 tons. The mass of matter, therefore, carried down annually would, according to this estimate, more than equal in weight and bulk forty-two of the great pyramids of Egypt, and that borne down in the four months of the rains would equal forty pyramids. But if, without any conjecture as to what may have been the specific gravity of the mud, we attend merely to the weight of solid matter actually proved by Mr. Everest to have been contained in the water, we find that the number of tons' weight which passed down in the 122 days of the rainy season was 339,413,760, which would give the weight of fifty-six pyramids and a half; and in the whole year 355,361,464 tons, or nearly the weight of sixty pyramids.

The base of the Great Pyramid of Egypt covers eleven acres, and its perpendicular height is about five hundred feet. It is scarcely possible to present any picture to the mind which will convey an adequate conception of the mighty scale of this operation, so tranquilly and almost insensibly carried on by the Ganges, as it glides through its alluvial plain, even at a distance of 500 miles from the sea. It may, however, be stated, that if a fleet of more than eighty Indiamen, each freighted with about 1,400 tons' weight of mud, were to sail down the river every hour of every day and night for four months continuously, they would only transport from the higher country to the sea a mass of solid matter equal to that borne down by the Ganges, even in this part of its course, in the four months of the flood season. Or the exertions of a fleet of about 2,000 such ships going down daily with the same burden, and discharging it into the gulf, would

be no more than equivalent to the operations of the great river.

The most voluminous current of lava which has flowed from Etna within historical times was that of 1669. Ferrara, after correcting Borelli's estimate, calculated the quantity of cubic yards of lava in this current at 140,000,000. Now this would not equal in bulk one-fifth of the sedimentary matter which is carried down in a single year by the Ganges, past Ghazepoor, according to the estimate above explained; so that it would require five grand eruptions of Etna to transfer a mass of lava from the subterranean regions to the surface, equal in volume to the mud carried down in one year to Ghazepoor.

Colonel R. Strachey, of the Bengal Engineers, has remarked to me, not only that Ghazepoor, where Mr. Everest's observations were made, is 500 miles from the sea, but that the Ganges has not been joined there by its most important feeders. These drain upon the whole 750 miles of the Himalaya, and no more than 150 miles of that mountain-chain have sent their contributions to the main trunk at Ghazepoor. Below that place, the Ganges is joined by the Gogra, Gunduk, Khosee, and Teesta from the north, to say nothing of the Sone flowing from the south, one of the largest of the rivers which rise in the table-land of Central India. (See map, fig. 43, p. 468.) Moreover, the remaining 600 miles of the Himalaya comprise that eastern portion of the basin where the rains are heaviest. (See above, p. 324.) The quantity of water, therefore, carried down to the sea may probably be four or five times as much as that which passes Ghazepoor.

The Brahmapootra, according to Major Wilcox,* in the month of January, when it is near its minimum, discharges 150,000 cubic feet of water per second at Gwalpara, not many miles above the head of its delta. Taking the proportions observed at Ghazepoor at the different seasons as a guide, the probable average discharge of the Brahmapootra for the whole year may be estimated at about the same as that of the Ganges. Assuming this; and secondly,

* Asiatic Researches, vol. xvii. p. 466.

in order to avoid the risk of exaggeration, that the proportion of sediment in their waters is about a third less than Mr. Everest's estimate, the mud borne down to the Bay of Bengal in one year would equal 40,000 millions of cubic feet, or between six and seven times as much as that brought down to Ghazepoor, according to Mr. Everest's calculations in 1831, and five times as much as that conveyed annually by the Mississippi to the Gulf of Mexico.

Colonel Strachey estimates the annually inundated portion of the delta at 250 miles in length by 80 in breadth, making an area of 20,000 square miles. The space south of this in the bay, where sediment is thrown down, may be 300 miles from E. to W. by 150 N. and S., or 45,000 square miles, which, added to the former, gives a surface of 65,000 square miles, over which the sediment is spread out by the two rivers. Suppose then the solid matter to amount to 40,000 millions of cubic feet per annum, the deposit, he observes, must be continued for forty-five years and three-tenths to raise the whole area a height of one foot, or 13,600 years to raise it 300 feet; and this, as we have seen, is much less than the thickness of the fluviatile strata actually penetrated (and the bottom not reached) by the auger at Calcutta.

Nevertheless we can by no means deduce from these data alone what will be the future rate of advance of the delta, nor even predict whether the land will gain on the sea, or remain stationary. At the end of 13,000 years the bay may be even less shallow than now, provided a moderate depression, corresponding to that experienced in part of Greenland for many centuries, shall take place (see p. 128). A subsidence quite insensible to the inhabitants of Bengal, not exceeding two feet three inches in a century, would be more than sufficient to counterbalance all the efforts of the two mighty rivers to extend the limits of their delta. We have seen that the Artesian borings at Calcutta attest, what the vast depth of the 'swatch' may also perhaps indicate, that the antagonist force of subsidence has predominated for ages over the influx of fluviatile mud, preventing it from raising the plains of Bengal, which now at Calcutta are only a few

inches above the level, or from filling up a larger portion of the bay.

CONCLUDING REMARKS ON DELTAS.

Convergence of deltas.—If we possessed an accurate series of maps of the Adriatic for many thousand years, our retrospect would, without doubt, carry us gradually back to the time when the number of rivers descending from the mountains into that gulf by independent deltas was far greater. The deltas of the Po and the Adige, for instance, would separate themselves within the Post-Tertiary era, as, in all probability, would those of the Isonzo and the Torre. If, on the other hand, we speculate on future changes, we may anticipate the period when the number of deltas will greatly diminish; for the Po cannot continue to encroach at the rate of a mile in a hundred years, and other rivers to gain as much in six or seven centuries upon the shallow gulf, without new junctions occurring from time to time; so that Eridanus, 'the king of rivers,' will continually boast a greater number of tributaries. The Ganges and the Brahmapootra have perhaps become partially confluent in the same delta within the historical, or at least within the human, era; and the date of the junction of the Red River and the Mississippi would, in all likelihood, have been known, if America had not been so recently discovered. The union of the Tigris and the Euphrates must undoubtedly have been one of the modern geographical changes of our earth, for Sir Henry Rawlinson informs me (1853) that the delta of those rivers has advanced two miles in the last sixty years, and is supposed to have encroached about forty miles upon the Gulf of Persia in the course of the last twenty-five centuries.

When the deltas of rivers, having many mouths, converge, a partial union at first takes place by the confluence of some one or more of their arms; but it is not until the main trunks are connected above the head of the common delta, that a complete intermixture of their joint waters and sediment takes place. The union, therefore, of the Po and Adige, and of the Ganges and Brahmapootra, is still incom-

plete. If we reflect on the geographical extent of surface drained by rivers such as now enter the Bay of Bengal, and then consider how complete the blending together of the greater part of their transported matter has already become, and throughout how vast a delta it is spread by numerous arms, we no longer feel so much surprise at the area occupied by some ancient formations of homogeneous mineral composition. But our surprise will be still farther lessened when we afterwards enquire (Ch. XXII.) into the action of tides and currents in disseminating sediment.

Age of existing deltas.—If we could take for granted, that the relative level of land and sea had remained stationary ever since all the existing deltas began to be formed—could we assume that their growth commenced at one and the same instant when the present continents acquired their actual shape—we might understand the language of geologists who speak of 'the epoch of existing continents.' They endeavour to calculate the age of deltas from this imaginary fixed period; and they calculate the gain of new land upon the sea, at the mouth of rivers, as having begun everywhere simultaneously. But the more we study the history of deltas the more we become convinced that upward and downward movements of the land and contiguous bed of the sea have exerted, and continue to exert, an influence on the physical geography of many hydrographical basins, on a scale comparable in magnitude or importance to the amount of fluviatile deposition effected in an equal lapse of time. In the basin of the Mississippi, for example, proofs both of descending and ascending movements, to a vertical amount of several hundred feet, can be shown to have taken place since the existing species of land and fresh-water shells lived in that region.*

The deltas also of the Po and Ganges have each, as we have seen (pp. 422 and 476), when probed by the Artesian auger, borne testimony to a gradual subsidence of land to the extent of several hundred feet—old terrestrial surfaces or 'dirt-beds,' turf, peat, forest-land, having been pierced at various depths.

* Lyell's Second Visit to the United States, vol. ii. chap. 34.

The changes of level at the mouth of the Indus in Cutch (see below, Ch. XXVIII.), and those of New Madrid in the valley of the Mississippi (see p. 453 and Ch. XXVIII.), are equally instructive, as demonstrating unceasing fluctuations in the levels of those areas into which running water is transporting sediment. If, therefore, the exact age of all modern deltas could be known, it is scarcely probable that we should find any two of them in the world to have coincided in date, or in the time when their earliest deposits originated.

Grouping of strata in deltas.—The changes which have taken place in deltas, even within the times of history, may suggest many important considerations in regard to the manner in which subaqueous sediment is distributed. If a lake, for example, be encircled on two sides by lofty mountains, receiving from them many rivers and torrents of different sizes, and if it is bounded on the other sides, where the surplus waters issue, by a comparatively low country, it is not difficult to define some of the leading geological features which must characterise the lacustrine formation, when this basin shall have been gradually converted into dry land by the influx of sediment.

The detritus washed down by rivers and torrents from the adjoining heights to the edge of the lake would sink at once into deep water, all the heavier pebbles and sand subsiding near the shore. The finer mud would be carried somewhat farther out, but not to the distance of many miles, for the greater part, as is seen where the Rhone enters the Lake of Geneva, falls down in clouds to the bottom, not far from the river's mouth. Thus alluvial tracts are formed near the shore at the mouths of every torrent and river; pebbles and sand are then transported farther from the mountains; but in their passage they decrease in size by attrition, and are in part converted into mud and sand. At length some of the numerous deltas, which are all directed towards a common centre, approach near to each other; those of adjoining torrents become united, and each is merged, in its turn, in the delta of the largest river, which advances most rapidly into the lake, and renders all the minor streams, one after the other, its tributaries. The various

mineral ingredients of all are thus blended together into one homogeneous mixture, and the sediment is poured out from a common channel into the lake.

As the average size of the transported particles decreases, while the force and volume of the main river augments, the newer deposits are diffused continually over a wider area, and are consequently more horizontal than the older. When at first there were many independent deltas near the borders of the basin, their separate deposits differed entirely from each other; one may have been charged, like the Arve where it joins the Rhone, with white sand and sediment derived from granite—another may have been black, like many streams in the Tyrol, flowing from the waste of decomposing rocks of dark slate—a third may have been coloured by ochreous sediment, like the Red River in Louisiana—a fourth, like the Elsa in Tuscany, may have held much carbonate of lime in solution. At first they would each form distinct deposits of sand, gravel, limestone, marl, or other materials; but after their junction, new chemical combinations and a distinct colour would be the result, and the particles, having been conveyed ten, twenty, or a greater number of miles over alluvial plains, would become finer. The more ancient system of strata would be composed for the most part of coarser materials, and would sometimes dip at a considerable angle, especially if consisting of beds of pebbles. The beds in the newer group would, on the whole, be finer-grained, and more homogeneous in colour and mineral composition, throughout large areas. But, although the law of arrangement here alluded to would cause the older or more littoral to be characterised in great part by coarser materials than the newer group, this latter, as it is advanced to a great distance from the shore, would be thrown down, not immediately on older rocks, but on strata made up of the finest mud which had been carried out to great distances when the littoral deltas first began to form. For this reason some of the newer strata of sand or coarser materials are often found to overlie an older set of much finer grain. By reflecting on these facts, we see that the law of arrangement must be very complex, more especially the relation between the relative

age of the different groups of sediment and the fineness of their component materials.

In those deltas where the tides and strong marine currents interfere, the above description would only be applicable with certain modifications. If a series of earthquakes accompany the growth of a delta, and change the levels of the land from time to time, as in the region where the Indus now enters the sea, the phenomena will depart still more widely from the ordinary type. If, after a protracted period of rest, a delta sink down, pebbles may be borne along in shallow water near the foot of the boundary hills, so as to form conglomerates overlying the fine mud previously thrown into deeper water in the same area.

Causes of stratification in deltas.—The stratified arrangement, which is observed to prevail so generally in aqueous deposits, is most frequently due to variations in the velocity of running water, which cannot sweep along particles of more than a certain size and weight when moving at a given rate. Hence, as the force of the stream augments or decreases, the materials thrown down in successive layers at particular places are rudely sorted, according to their dimensions, form, and specific gravity. Where this cause has not operated, as where sand, mud, and fragments of rock are conveyed by a glacier, a confused heap of rubbish devoid of all stratification is produced.

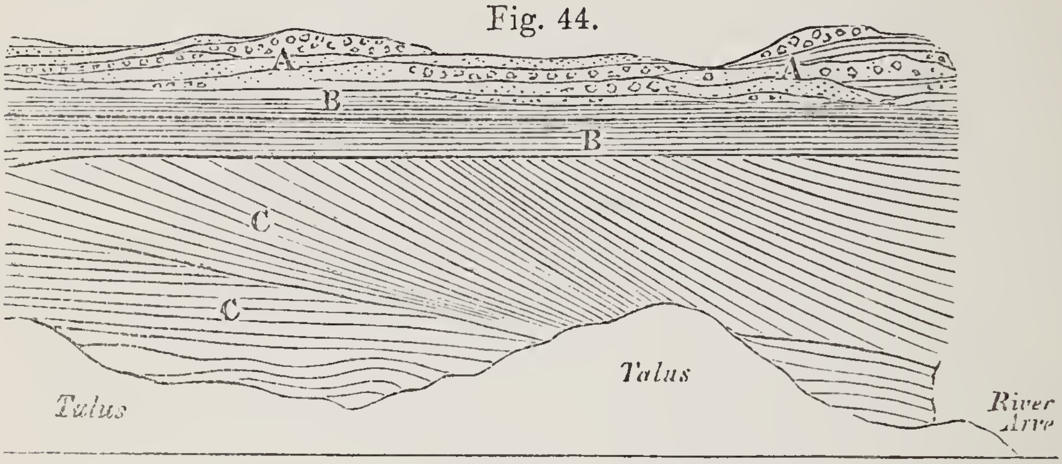
Natural divisions are also occasioned in deltas by the interval of time which separates annually the deposition of matter during the periodical rains, or melting of the snow upon the mountains. The deposit of each year may acquire some degree of consistency before that of the succeeding year is superimposed. A variety of circumstances also gives rise annually, or sometimes from day to day, to slight variations in colour, fineness of the particles, and other characters, by which alternations of strata distinct in texture and mineral ingredients must be produced. Thus, for example, at one period of the year, drift wood may be carried down, and, at another, mud, as was before stated to be the case in the delta of the Mississippi; or at one time, when the volume and velocity of the stream are greatest, pebbles and sand

may be spread over a certain area, over which, when the waters are low, fine matter or chemical precipitates are formed. During inundations, the turbid current of fresh water often repels the sea for many miles; but when the river is low, salt water again occupies the same space. When two deltas are converging, the intermediate space is often, for reasons before explained, alternately the receptacle of different sediments derived from the converging streams (see p. 454). The one is, perhaps, charged with calcareous, the other with argillaceous matter; or one sweeps down sand and pebbles, the other impalpable mud. These differences may be repeated, with considerable regularity, until a thickness of hundreds of feet of alternating beds is accumulated. The multiplication, also, of shells and corals in particular spots, and for limited periods, gives rise occasionally to lines of separation, and divides a mass which might otherwise be homogeneous into distinct strata.

An examination of the shell marl now forming in the Scotch lakes, or the sediment termed 'warp,' which subsides from the muddy water of the Humber and other rivers, shows that recent deposits are often composed of a great number of extremely thin layers, either even or slightly undulating, and preserving a general parallelism to the planes of stratification. Sometimes, however, the laminæ in modern strata are disposed diagonally at a considerable angle, which appears to take place where there are conflicting movements in the waters. In January 1829 I visited, in company with Professor L. A. Necker, of Geneva, the confluence of the Rhone and Arve, when those rivers were very low, and were cutting channels through the vast heaps of débris thrown down from the waters of the Arve in the preceding spring. One of the sand-banks which had formed in the spring of 1828, where the opposing currents of the two rivers neutralised each other, and caused a retardation in the motion, had been undermined; and fig. 44 on the following page is an exact representation of the arrangement of laminæ exposed in a vertical section. The length of the portion here seen is about twelve feet, and the height five. The strata A A consist of irregular alternations of pebbles and sand in

undulating beds: below these are seams of very fine sand, B B, some as thin as paper, others about a quarter of an inch thick. The strata C C are composed of layers of fine greenish-grey sand as thin as paper. Some of the inclined beds will be seen to be thicker at their upper, others at their lower, extremity, the inclination of some being very considerable.

Fig. 44.



Section of a sand-bank in the bed of the Arve at its confluence with the Rhone, showing the stratification of deposits where currents meet.

These layers must have accumulated one on the other by lateral apposition, probably when one of the rivers was very gradually increasing or diminishing in velocity, so that the point of greatest retardation caused by their conflicting currents shifted slowly, allowing the sediment to be thrown down in successive layers on a sloping bank. The same phenomenon is exhibited in older strata of all ages.*

If the bed of a lake or of the sea be sinking, whether at a uniform or an unequal rate, or oscillating in level during the deposition of sediment, these movements will give rise to a different class of phenomena, as, for example, to repeated alternations of shallow-water and deep-water deposits, each with peculiar organic remains, or to frequent repetitions of similar beds formed at a uniform depth, and enclosing the same organic remains, and to other results too complicated and varied to admit of enumeration here.

Formation of conglomerates.—Along the base of the Maritime Alps, between Toulon and Genoa, the rivers, with few exceptions, are now forming strata of conglomerate and sand. Their channels are often several miles in breadth, some of

* See Elements of Geology, 6th ed. p. 16, and Student's Elements, p. 17.

them being dry, and the rest easily forded for nearly eight months in the year, whereas during the melting of the snow they are swollen, and a great transportation of mud and pebbles takes place. In order to keep open the main road carried along the sea-coast from France to Italy, it was necessary to remove annually great masses of shingle brought down during the flood season. A portion of the pebbles are seen in some localities, as near Nice, to form beds of shingle along the shore, but the greater part are swept into a deep sea. The small progress made by the deltas of minor rivers on this coast need not surprise us, when we recollect that there is sometimes a depth of two thousand feet at a few hundred yards from the beach, as near Nice. Similar observations might be made respecting a large proportion of the rivers in Sicily, and, among others, respecting that which, immediately north of the port of Messina, hurries annually vast masses of granitic pebbles into the sea.

I may here conclude my remarks upon deltas, observing that, imperfect as is our information of the changes which they have undergone within the last three thousand years, they are sufficient to show how constant an interchange of sea and land is taking place on the face of our globe. In the Mediterranean alone, many flourishing inland towns, and a still greater number of ports, now stand where the sea rolled its waves since the era of the early civilisation of Europe. If we could compare with equal accuracy the ancient and actual state of all the islands and continents, we should probably discover that millions of our race are now supported by lands situated where seas and lakes prevailed in earlier ages. While in many districts land animals and forests now abound where ships once sailed, it is no less true, on the other hand, that inroads of the ocean and submergence of land by the sinking down of the earth's crust have taken place over equally wide areas. When all these revolutions, gradually brought about by aqueous and igneous agency, are duly considered, we shall, perhaps, acknowledge the justice of the conclusion of Aristotle, who declared that the whole land and sea on our globe periodically changed places.*

* See p. 22.

CHAPTER XX.

DESTROYING AND TRANSPORTING EFFECTS OF TIDES AND CURRENTS.

DIFFERENCES IN THE RISE OF THE TIDES—CAUSES OF CURRENTS—LAGULLAS AND GULF CURRENTS—CURRENT IN LAKE ERIE—SURFACE CURRENT INTO THE MEDITERRANEAN DUE TO EXCESS OF EVAPORATION—NO PERMANENT UNDER-CURRENT IN THE STRAITS OF GIBRALTAR, BUT TIDAL ACTION TO THE BOTTOM—CONTRAST OF TEMPERATURE BETWEEN THE MEDITERRANEAN AND ATLANTIC—CURRENTS IN THE BLACK SEA—VELOCITY OF CURRENTS—GENERAL OCEANIC CIRCULATION—ACTION OF THE SEA ON THE BRITISH COAST—SHETLAND ISLANDS—LARGE BLOCKS REMOVED—ISLES REDUCED TO CLUSTERS OF ROCKS—ORKNEY ISLES—WASTE OF EAST COAST OF SCOTLAND—AND EAST COAST OF ENGLAND—WASTE OF THE CLIFFS OF HOLDERNESS, NORFOLK, AND SUFFOLK—ECCLES CHURCH IN 1839 AND 1862—SAND-DUNES HOW FAR CHRONOMETERS—SILTING UP OF ESTUARIES—YARMOUTH ESTUARY—SUFFOLK COAST—DUNWICH—ESSEX COAST—ESTUARY OF THE THAMES—GOODWIN SANDS—COAST OF KENT—FORMATION OF THE STRAITS OF DOVER—SOUTH COAST OF ENGLAND—SUSSEX—HANTS—DORSET—PORTLAND—ORIGIN OF THE CHESIL BANK—TOR BAY—ST. MICHAEL'S MOUNT, CORNWALL—COAST OF BRITTANY.

Although the movements of great bodies of water, termed tides and currents, are in general due to very distinct causes, their effects cannot be studied separately; for they produce, by their joint action, aided by that of the waves, those changes which are objects of geological interest. These forces may be viewed in the same manner as we before considered rivers—first, as employed in destroying portions of the solid crust of the earth, and removing them to other places; secondly, as productive of new strata.

Tides.—It would be superfluous at the present day to offer any remarks on the cause of the tides. They are not perceptible in lakes or in most inland seas; in the Mediterranean even, deep and extensive as is that sea, they are scarcely sensible to ordinary observation, their effects being quite subordinate to those of the winds and currents. In some places, however, as in the Straits of Messina, there is an ebb and flow to the amount of two feet and upwards; at Naples of twelve or thirteen inches; and at Venice, according to

Rennell, of five feet.* In the Syrtes, also, of the ancients, two wide shallow gulfs, which penetrate very far within the northern coast of Africa between Carthage and Cyrene, the rise is said to exceed five feet.† The effect of the tide in the celebrated Straits of Euripus in Greece is very remarkable. These straits at Chalcis or Negropont are only about fifty feet wide and twenty feet deep, and Captain Spratt observed during his survey of the Mediterranean that for about four days before and five after the full and new moon the tide runs with great regularity six hours to the north and then six hours to the south at a rate of several miles an hour. The rise and fall is about one foot on the southern side of the straits and as much as twenty-six inches on the northern. At other times he found that the tide was absorbed by the influence of local winds and was very irregular.

In islands remote from any continent, the ebb and flow of the ocean is very slight, as at St. Helena, for example, where it is rarely above three feet.‡ In any given line of coast, the tides are greatest in narrow channels, bays, and estuaries, and least in the intervening tracts where the land is prominent. Thus, at the entrance of the estuary of the Thames and Medway, the rise of the spring tides is eighteen feet; but when we follow our eastern coast from thence northward, towards Lowestoft and Yarmouth, we find a gradual diminution, until, at the places last mentioned, the highest rise is only seven or eight feet. From this point there begins again to be an increase, so that at Cromer, where the coast again retires towards the west, the rise is sixteen feet; and towards the extremity of the gulf called 'the Wash,' as at Lynn and in Boston Deeps, it is from twenty-two to twenty-four feet, and in some extraordinary cases twenty-six feet. From thence again there is a decrease towards the north, the elevation at the Spurn Point being from nineteen to twenty feet, and at Flamborough Head and the Yorkshire coast from fourteen to sixteen feet.§

At Milford Haven, in Pembrokeshire, at the mouth of the

* Geog. of Herod. vol. ii. p. 331.

† Ibid. p. 328.

‡ Romme, Vents et Courans, vol. ii. p. 2. Rev. F. Fallows, Quart. Journ. of Science, March 1829.

§ The heights of these tides were given me by the late Captain Hewitt, R.N.

Bristol Channel, the tides rise thirty-six feet; and at King-Road, near Bristol, forty-two feet. At Chepstow on the Wye, a small river which opens into the estuary of the Severn, they reach fifty feet and sometimes sixty-nine, and even seventy-two feet.* A current which sets in on the French coast, to the west of Cape La Hague, becomes pent up by Guernsey, Jersey, and other islands, till the rise of the tide is from twenty to forty-five feet, which last height it attains at Jersey, and at St. Malo, a seaport of Brittany. The tides in the Basin of Mines, at the head of the Bay of Fundy, in Nova Scotia, rise to the height of seventy feet. There are, however, some coasts where the tides seem to offer an exception to the rule above mentioned; for while there is scarcely any rise in the estuary of the Plata in South America, there is an extremely high tide on the open coast of Patagonia, farther to the south. Yet even in this region the tides reach their greatest elevation (about fifty feet) in the Straits of Magellan, and so far at least they conform to the general rule.

Causes of currents.—That movements of no inconsiderable magnitude should be impressed on a wide expanse of ocean, by winds blowing for many months in one direction, may easily be conceived, when we observe the effects produced in our own seas by the temporary action of the same cause. It is well known that a strong south-west or north-west wind invariably raises the tide to an unusual height along the west coast of England and in the Channel, and that a north-west wind of any continuance causes the Baltic to rise two feet and upwards above its ordinary level. Smeaton ascertained by experiment, that in a canal four miles in length, the water was kept up four inches higher at one end than at the other merely by the action of the wind along the canal; and the late Major Rennell informs us that a large piece of water, ten miles broad, and generally only three feet deep, has, by a strong wind, had its waters driven to one side, and sustained so as to become six feet deep, while the windward side was laid dry.†

* On the authority of Admiral Sir F. Beaufort, R.N.

† Rennell on the Channel Current.

As water, therefore, he observes, when pent up so that it cannot escape, acquires a higher level, so in a place *where it can escape,* the same operation produces a current; and this current will extend to a greater or less distance, according to the force by which it is produced.

In such large bodies of water as the North American lakes, the continuance of a strong wind in one direction often causes the accumulation of the water on the leeward side; and while the equilibrium is being restored powerful currents are occasioned. In October 1833 a strong current in Lake Erie, caused partly by the set of the waters towards the outlet of the lake, and partly by the prevailing wind, burst a passage through the extensive peninsula called Long Point, and soon excavated a channel more than nine feet deep and nine hundred feet wide, which was afterwards widened and deepened.* On the opposite, or southern coast of this lake, in front of the town of Cleveland, the degradation of the cliffs had been so rapid for several years preceding a survey made in 1837 as to threaten many towns with demolition.†

Major Rennell ‡ has divided currents according to their origin into drift and stream currents; the former being due to constant and prevalent winds impelling the surface water to leeward until it meets with some obstacle which stops it and occasions an accumulation, this accumulation then giving rise to a stream-current. The obstacle may be either land or banks or a stream-current already formed. A stream-current may be of any bulk, or depth, or velocity; a drift-current is shallow, and rarely exceeds in velocity the rate of half a mile an hour.

One of the chief oceanic currents is that which flows through the Mozambique Channel, and there skirts the south-east coast of Africa, having a breadth of ninety miles and a velocity of between two and four miles an hour. On reaching the Cape, it is turned westward by the Lagullas, a great shoal or rather a submerged chain of mountains, which,

* From notes given me by Capt. Bayfield, R.N.

† Silliman's Journ. vol. xxxiv. p. 349.

‡ Investigation of the Currents of the Atlantic Ocean, p. 21. London, 1832.

rising from a deep ocean, comes within 100 fathoms of the surface. The deflection of this current, says Rennell, proves that it is more than 100 fathoms deep, otherwise the main body of it would pass across the bank instead of being deflected westward, so as to flow round the Cape of Good Hope. It is then joined by a current from the south or from antarctic latitudes, and, continuing its course, takes a northerly direction along the western coast of Africa, till it reaches the Bight or Bay of Benin. There it is turned westward, partly by the form of the coast and partly perhaps by meeting the Guinea current, which runs from the north into the same great bay. From the centre of this bay proceeds what is called the equatorial current of the Atlantic, having a width of from 160 to 450 nautical miles, and holding a westerly course across that ocean, which it traverses from the coast of Guinea to that of Brazil. The whole length is said to be about 4,000 geographical miles, and its velocity from twenty-five to seventy-nine miles per day, the mean rate being about thirty miles.

On approaching the N.E. promontory of South America, called Cape St. Roque, it divides itself into two parts, one portion of which pursues a southerly course along the coast of Brazil, while the principal part of it flows westward, and, skirting the coast of Guiana, is reinforced by the waters of the Amazons and Orinoco. After passing the island of Trinidad, it expands and contributes in some degree to raise the waters of the Caribbean Sea and Gulf of Mexico, which are also supposed to be heaped up by the blowing of the north-east trade winds—a combination of circumstances which gives rise to the Gulf-stream.

The last-mentioned current has already been alluded to in the twelfth chapter (p. 239) as moderating the cold of a large part of the northern hemisphere. A curious fact is related by General Sabine as illustrating the combined effects of the equatorial and Gulf currents last alluded to. He happened to visit the African coast in 1822, when a vessel was wrecked at Cape Lopez, near the equator, and the year after he was at Hammerfest, in Norway, near the North Cape of Europe, when casks of palm oil derived from the same wrecked

vessel were thrown on shore. They had crossed the Atlantic south of the line in a direction from east to west, made the circuit of the West Indian Islands, and then recrossed the Atlantic north of the line from west to east. The last or northern part of their course may possibly, says General Sabine, have been due not wholly to the original impulse of the Gulf-stream, but to the west and south-west winds which prevail to the northward of the trades.

From the above statements we may understand why Rennell has characterised some of the principal currents as oceanic rivers, which he describes as being from 50 to 250 miles in breadth, and having a rapidity exceeding that of the largest navigable rivers of the continents, and so deep as to be sometimes obstructed, and occasionally turned aside, by banks, the tops of which do not rise within forty, fifty, or even one hundred fathoms of the surface of the sea.*

Currents flowing alternately in opposite directions are occasioned by the rise and fall of the tides. The effect of this cause, as we shall see in the sequel, is most striking in estuaries and channels between islands.

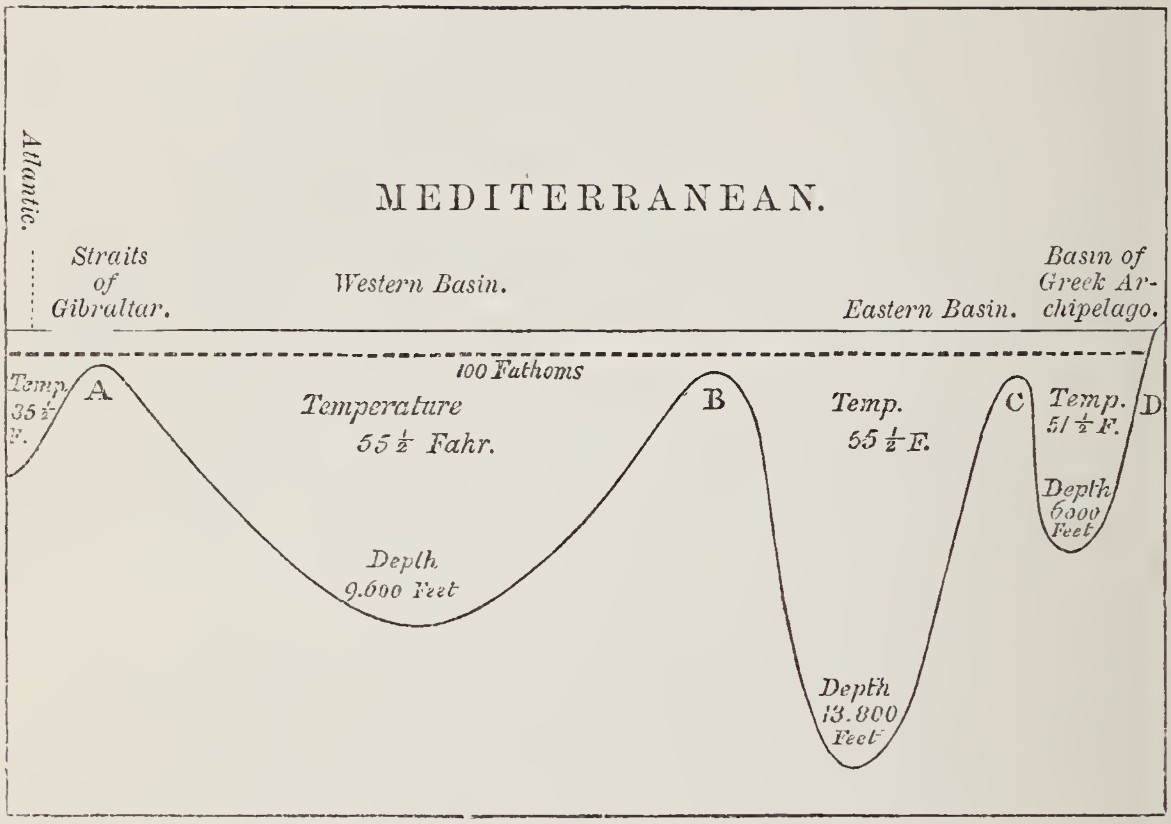
Current into the Mediterranean due to excess of evaporation.—Another cause of oceanic currents is evaporation by solar heat. Of this the current which sets constantly from the Atlantic into the Mediterranean is a good example. The late Admiral Smyth found, during his survey, that a central current ran constantly at the rate of from three to six miles an hour eastward into the inland sea, the body of water being three miles and a half wide. But there are also two lateral currents—one on the European, and one on the African side; each of them from a quarter of a mile to two miles broad, and flowing at about the same rate as the central stream. These lateral currents ebb and flow with the tide, setting alternately into the Mediterranean and into the Atlantic. But it is a generally received opinion that, in spite of their action, there is an excess of water flowing inwards, to make up for the loss which the Mediterranean suffers by evaporation. For the winds blowing from the shores of Africa are

* Rennell on Currents, p. 58.

hot and dry, and the temperature of the air investing the great inland sea, as well as that of the water, is higher on an average than the eastern part of the Atlantic Ocean in the same latitude.

The western basin of the Mediterranean, or that lying to the west of Sicily, between A, B (fig. 45), was estimated

Fig. 45.



Section of the Mediterranean Basins.

A. Submarine ridge, about 167 fathoms deep, between Capes Trafalgar and Spartel.

B. Adventure and Medina Banks, about 200 fathoms deep, between Sicily and Africa.

C. Ridge, about 200 fathoms deep, between the Eastern Basin and Greek Archipelago.

D. Asia Minor.

by Captain Spratt in 1845 to have, at depths below one hundred fathoms, a temperature of about 20° F. higher than that of the Atlantic in the same latitude.* This extraordinary difference would be impossible but for the existence of a submarine barrier of rock (A, fig. 45) which

* Capt. Spratt estimated the temperatures of the two seas at $59\frac{1}{2}°$ and $39\frac{1}{2}°$. Since then more perfect thermometers have been brought into use, which show a temperature of $55\frac{1}{2}°$ in the Mediterranean, and $35\frac{1}{2}°$ in the Atlantic. As, however, this error affects both seas equally, it does not in any way vitiate the previous generalisation.

was found by Admiral Smyth to extend from Cape Trafalgar to Cape Spartel, which are only 22 miles apart. He ascertained that the crest of this ridge could in no part be lower than 220 fathoms from the surface; but Capt. Spratt informs me that the French surveyors, in their more recent surveys of 1854 and 1863, have proved that the deepest soundings, which are near the Tangier side, do not exceed 167 fathoms. The ridge being from five to seven miles broad, the shallowest part of the continuous crest may even now have escaped observation, and it forms a parting wall by which the colder waters of the Atlantic are prevented from invading the Mediterranean.* It was formerly supposed that the saltness of the water increased in proportion to the depth; but Captain Spratt's observations do not bear out this conclusion, though the Ægean is slightly fresher at the surface near the Dardanelles, from which a current charged with much river water is constantly flowing.

The question was raised as much as 200 years ago, in 1673, by Dr. Smith, whether there is not a counter-under-current from the Mediterranean to the Atlantic, pouring back the surplus water which is over and above that required to counterbalance evaporation, and the idea of such a counter-current was again suggested in 1724 by the following circumstance. M. de l'Aigle, commander of a privateer called the 'Phœnix,' of Marseilles, gave chase to a Dutch merchant-ship near Ceuta Point, and coming up with her in the middle of the gut, between Tarifa and Tangier, gave her one broadside, which directly sunk her. A few days after, the sunken ship, with her cargo of brandy and oil, was cast ashore near Tangier, which is at least four leagues to the westward of the place where she went down, and to which she must have floated in a direction contrary to the course of the *central* current.† This fact, however, affords no evidence of an under-current, because the ship, when it approached the coast, would necessarily be within the influence of a lateral current, which running westward twice every twenty-four hours, might have brought back the vessel to Tangier.

* Capt. Spratt, Travels and Researches in Crete, 1865.

† Phil. Trans. 1724.

An attempt to test the truth of a return under-current was made in 1870, under the superintendence of Captain Calver, R.N., in command of the surveying vessel 'Porcupine,' sent out by the Admiralty. Dr. Carpenter, who accompanied the expedition, inferred from the experiments then made* that there was a constant current flowing at the depth of 250 fathoms out of the Mediterranean, an opinion opposed to that which I had expressed in my former edition (1867, p. 563), as such a current appeared to me irreconcilable with the shallowness of the water over the submarine barrier before mentioned; and I found that Captain Spratt, to whom I was indebted for much of my former knowledge, agreed with me in thinking that the proofs of the permanent under-current insisted upon by Dr. Carpenter were inconclusive, though he pointed out at the same time that 'in such a strait as that of Gibraltar, where there are *tidal influences* combined with the general insets from the Atlantic, an under-current at certain times is a possibility.' † Last autumn the Admiralty, in further pursuance of the observations of 1870, sent out the surveying vessel 'Shearwater,' commanded by Captain Nares, R.N., and provided with more perfect apparatus for making experiments upon the under-current. From the report of Captain Nares, kindly lent me by Admiral Richards, we learn that the outward movement observed by the 'Porcupine' below the inflowing current is, not a permanent under-current, but the result of the Mediterranean tide, which extends to the bottom of the Straits, running alternately for several hours westward and for an equal number of hours eastward, according to the flood and ebb of the tide, as shown by the rise and fall of the water on the shore.

This tide, when in a direction opposed to that of the surface current which flows in from the Atlantic, checks to a certain extent that influx, and when aided by easterly winds was found by Captain Nares to cause, even at the surface, a set to the westward. Its action appears, however, to be much more regular in the depths of the Straits where it is less interfered with either by winds or by the surface inflow.

* See Royal Society Proc. vol. xix. 1870, p. 146.

† Royal Soc. Proc. vol. xix. 1871, p. 546.

On comparing the results of the experiments made by the surveying officers in the two expeditions, I find nothing irreconcilable or antagonistic. The outward movement reported by Captain Calver is confirmed by Captain Nares, with the additional fact that, during the ebb of the tide this movement is reversed, thus proving that the under-current is the effect of tidal action. Captain Nares states that the bottom water in the strait 'ran to the westward more rapidly with the flood than it ran to the eastward with the ebb.' But he does not lay much stress on this point; and Admiral Richards informs me that the observations of the 'Shearwater' lasting only six days, and chiefly during the prevalence of easterly winds, were in his opinion too few to decide whether the volume of water carried out to the Atlantic was in excess of that carried in.

The Black Sea being situated in a higher latitude than the Mediterranean, and being the receptacle of rivers flowing from the north, is much colder, and its loss by conversion into vapour less considerable. It contributes a steady supply of water to the Mediterranean, by a current flowing outwards, for the most part of the year, through the Dardanelles at a rate of two or three miles an hour. The discharge, however, at the Bosphorus into the Sea of Marmora is so small, when compared to the volume of water carried in by rivers, as to imply a great amount of evaporation even in the Black Sea.

There has been some difficulty in explaining how the Black Sea maintains its salinity in spite of the vast body of fresh water brought down into it by rivers. But some light is thrown upon this point by Captain Spratt's experiments at Constantinople and Kertch during the years 1853 to 1856. It was then ascertained that, although a current of the Black Sea flows for a great part of the year across the Sea of Marmora and through the Dardanelles, yet there is for several days in the year a strong reverse current into the Black Sea from the Mediterranean.* This reverse current occurs mainly during the autumn and winter months, when the Black Sea rivers are at their lowest, and when strong westerly gales in the Mediterranean and Ægean raise the

* Spratt's Crete, vol. ii. p. 349.

waters of the latter to a higher level than the Black Sea. In these cases the influx is even greater than the outflowing current at other periods, and thus maintains in the Sea of Marmora a salinity equal to that of the Mediterranean, and in the Black Sea rather more than half that amount. The depth of the ridge across the Bosphorus or channel of Constantinople is not more than 20 fathoms, and that of the Dardanelles about 30, so that the depth of the ordinary currents carried eastward by this cause is limited by the shallowness of these outlets.

Evaporation by solar heat, besides affecting the level of adjoining seas in the way above mentioned, gives origin, by the formation of aqueous vapour and rain, to all the rivers which drain the land, and some of these are of such magnitude as to augment the volume and velocity of great oceanic currents. Thus the river Amazons, as General Sabine observed in 1822, preserves a velocity of nearly three miles an hour at a distance of upwards of 300 miles from its mouth, its original direction being scarcely altered, and the fresh water having only become partially mixed with that of the ocean. The river Plate, says Rennell, has still a velocity of a mile an hour, and a breadth of more than 800 miles, at a distance of not less than 600 miles from its mouth.

Greatest velocity of currents.—The ordinary velocity of the principal currents of the ocean is from one to three miles per hour; but when the boundary lands converge, large bodies of water are driven gradually into a narrow space, and then, wanting lateral room, are compelled to raise their level. Whenever this occurs, their velocity is much increased. The current which runs through the Race of Alderney, between the island of that name in the English Channel and the mainland, has a velocity of about eight miles an hour. Captain Hewitt found that in the Pentland Firth, the stream, in ordinary spring-tides, runs ten miles and a half an hour, and about thirteen miles during violent storms. The greatest velocity of the tidal current through the 'Shoots' or New Passage, in the Bristol Channel, is fourteen English miles an hour; and Captain King observed, in his survey of the Straits of Magellan, that the tide ran at the same rate

through the 'First Narrows,' and about eight geographical miles an hour in other parts of those straits.

When currents have been set in motion by some one or all of the forces enumerated in this chapter, namely, the winds, the tides, evaporation, and the influx of rivers, another cause comes into play in modifying their direction. I allude to the rotation of the earth on its axis, which, however, can only act when the current so raised happens to be from south to north or from north to south.

The principle on which this cause operates is probably familiar to the reader, as it has long been recognised in the case of the trade winds. Without enlarging, therefore, on the theory, it will be sufficient to offer an example of the mode of action alluded to. When a current flows from the Cape of Good Hope towards the Gulf of Guinea, it consists of a mass of water, which, on doubling the Cape, in lat. 35°, has a rotatory velocity of about 800 miles an hour; but when it reaches the line, where it turns westward, it has arrived at a parallel where the surface of the earth is whirled round at the rate of 1,000 miles an hour, or about 200 miles faster. If this great mass of water was transferred suddenly from the higher to the lower latitude, the deficiency of its rotatory motion, relatively to the land and water with which it would come into juxtaposition, would be such as to cause an apparent motion of the most rapid kind (of no less than 200 miles an hour) from east to west.

In the case of such a sudden transfer, the eastern coast of America, being carried round in an opposite direction, might strike against a large body of water with tremendous violence, and a considerable part of the continent might be submerged. The disturbance does not occur, because the water of the stream, as it advances gradually into new zones of the sea which are moving more rapidly, acquires by friction an accelerated velocity. Yet as this motion is not imparted instantaneously, the fluid is unable to keep up with the full speed of the new surface over which it is successively brought. Hence, to borrow the language of Herschel, when he speaks of the trade winds, 'it lags or hangs back, in a direction opposite to the earth's rotation, that is, from east

to west;' and thus a current, which would have run simply northwards from the Antarctic Ocean to the Equator but for the rotation, may acquire a relative direction towards the west.

A striking example in the northern hemisphere of a similar deflection westward is afforded by the polar current, which, loaded with floating ice, flows southward from the Arctic Sea in the neighbourhood of Spitzbergen, having a breadth of between 40 and 50 miles, and after passing the southern extremity of Greenland, then trends towards the west under the influence of the earth's rotation, that westerly tendency increasing as it enters latitudes of increased rotatory velocity. Here it unites with other cold and ice-laden currents from Baffin's Bay, and then continues its course towards the Labrador coast, and rounding Newfoundland descends along the eastern coast of the United States at a rate varying from half a mile to three-quarters of a mile an hour, forming a cold current about 250 fathoms in depth inside or westward of the Gulf-stream. This last stream affords an example of a motion exactly the converse of the Labrador current. Flowing at first from about lat. 20° N., it is impressed with a velocity of rotation of about 940 miles an hour, and runs to lat. 40°, where the earth revolves only at the rate of 766 miles, or 174 miles slower. In this case a relative motion of an opposite kind results; and the current retains an excess of rotatory velocity, tending continually to deflect it eastward. The two currents therefore have a tendency to keep separate, the one from an excess and the other from a deficiency of rotatory motion. In the region where the two streams run side by side we find the remarkable phenomenon known as the cold wall, an almost vertical division between the warmer waters of the Gulf-stream, which range from 60° to 85° Fahr., and the Labrador current, which, even at its surface, often has a temperature in the winter months 30° Fahr. lower than the warm stream flowing past it. Each of these currents has its own peculiar fauna, and Professor Bache found that the line of demarcation between them becomes more defined at the depth of 50 fathoms than at the surface. At what depth, owing to condensation, the Labrador current may acquire such specific gravity as to cause it to pass under the warmer

stratum is not yet well ascertained, but the low temperature of 40° Fahr. found off Florida at the depth of 300 fathoms while the surface has a temperature of 80° Fahr. would seem to be due to the action of the cold under-current.

This is one of the best illustrations of the grand scale on which the Arctic waters may restore equilibrium in regard to level and temperature by transferring bodily southwards large masses of cold water, not creeping along the bottom, but as above stated 250 fathoms in depth, and having all the characters of ordinary currents which have no doubt been created by the action of the wind and tide, and which do not derive their motion from mere differences in temperature and specific gravity between polar and equatorial waters. Those winds by which large ice-floes, after remaining for weeks in certain bays or coasts, are made to shift their quarters must give rise to drift-currents, and these to stream-currents; and if the Gulf-stream and other flows of warmer water from equatorial regions pour into the Arctic basin, they must escape in such streams as that seen on the coast of Labrador. The shallowness of Behring's Straits, which are only of the depth of those of Dover, would prevent any large outflow into the Pacific; and as the only known outlets from this cul-de-sac will therefore be through Baffin's Bay and between Spitzbergen and Greenland, this may account for the force and magnitude of the Labrador current.

Between Iceland and the Faroe Islands the Gulf-stream and Polar current fight, as Dr. Petermann expresses it,* for the mastery; and the result of this struggle is a sea striped with warm and cold areas, as was shown by Lord Dufferin in 1856, and by Wallich in the 'Bulldog' expedition commanded by Sir Leopold M'Clintock in 1860. These facts are particularly interesting as having been fully confirmed by the late deep-sea dredgings between the Faroe and Shetland Islands. Here Drs. Carpenter and Wyville Thomson found two areas which, although having the same temperature of 51° Fahr. at the surface, began to differ at the depth of 150 fathoms. The one area, inhabited by its own peculiar fauna, comprising large foraminifera and siliceous sponges of more

* Der Golf-strom, Geographische Mittheilungen. Justus Perthes. Band 16. 1870.

southern types, lost very little in temperature below 150 fathoms, and at a depth of 500 fathoms had still a warmth of 45° Fahr. The other, or cold area, lost temperature rapidly after the depth of 100 fathoms, and at one place below 350 fathoms was colder than the freezing point of fresh water. The water in this area gave proof of its northern origin by containing echinoderms and other organic remains proper to Norwegian and still higher latitudes. It has been objected that we have no right to attribute to the influence of the Gulf-stream the warmth of all the water which we may find in the Northern Atlantic above the normal temperature of the latitude. But when recognising the influence of that stream in the Atlantic we do not, as Dr. Petermann justly observes, refer the whole of it to the current which flows out of the Gulf of Mexico, or deny that it has received accessions upon its way: we rather retain the name of Gulf-stream just as we do that of a river from its source to its delta, although many tributaries coming from different regions may have swollen and modified its volume. The main fact that the Gulf-stream does reach the shores of Europe is proved by the well-known drifting of West Indian seeds to the coast of Ireland (see Vol. II. Chap. xl.), and doubtless the south-westerly winds which prevail so largely in the Atlantic must do much in propelling the superficial waters in the same direction as they are carried by the regular currents.

Oceanic circulation.—Besides those sensible currents arising from the various causes already mentioned, a theory of general oceanic circulation first propounded by Maury has lately been brought into prominence by Dr. Carpenter in order to account for the cold found at great depths both in temperate and tropical regions. Captain Shortland, in his line of soundings made in 1868 for the laying down of the electric cable between Aden and Bombay, found a temperature of 34°·3 Fahr. at a depth of 1,800 fathoms (11,400 feet), and in the cruise of the 'Porcupine' in 1869 the bottom temperature between latitudes 50° and 70° N. was in several cases found to be below the freezing point of fresh water. That these low temperatures cannot be caused by mere depth is evident from the fact that in the Mediterranean soundings have

been made to the depth of 13,800 feet, or nearly as deep as the Alps are high, without ever reaching a temperature below 55° Fahr. When we reflect therefore that the Aden line of telegraph is fifteen degrees north of the equator, and that cold water can only come to that spot from the southern hemisphere, we are brought to the conclusion that the whole of the equatorial abysses of the ocean are in some part at least traversed by a continuous mass of water not much above 32° Fahr.

It is an acknowledged fact that when salt water in arctic and antarctic latitudes is cooled to a temperature below that at which fresh water freezes, its greater specific gravity causes it to sink, but it does not become ice until it attains the temperature of 27° Fahr. or even 25° Fahr. if the saltness somewhat exceeds the average. If on arriving at the bottom it finds there water of less specific gravity it will displace it, and it is inferred that thus a movement will be induced towards warmer latitudes, producing what Dr Carpenter has well characterised as a 'creeping flow.' The direction of this movement must be governed by local conditions or the shape of the bed of the ocean, and it may take years in traversing the ninety degrees between the poles and the equator. Its progress may be so gradual as not to cause what in ordinary language would be termed oceanic currents, and may even be consistent with that perfect stillness found generally to prevail in the abysses of the ocean. Captain Spratt reminds us that during the soundings taken across the Atlantic the sounding line on several occasions coiled itself upon the sinker when some 200 or 300 fathoms more than the actual depth happened accidentally or intentionally to have been paid out from the ship, and thus the coils came up in a bunch together round the deep-sea lead. Such facts tell strongly against the existence of anything like a sensible current, but on the other hand they do not prove the water to be motionless, because the tension of the hempen sounding-line might be such as to afford some resistance to a slight and almost imperceptible movement, such as might still be sufficient in the course of time to convey cold water to all those submarine regions where there is a free communication, or where no continuous shoal or chain of submarine mountains intervenes.

If such a movement be taking place, however slowly, it must be counterbalanced by a return of water back from the equator to the poles, and how this may be readily effected will be evident to the reader after what has been said of the powerful effect of the winds on the surface of the ocean. It is quite unnecessary to seek for some recondite cause, such as the expansion of water by heat in the equatorial zone raising the level of the sea and causing a flow to the poles down a gently inclined plane. This theory, which is by no means a new one, was considered by Sir John Herschel in his 'Physical Geography,' where he shows that the slope between tropical and temperate latitudes, a distance of 3,000 or 4,000 miles, would be so insignificant that the accelerating force produced would not exceed one two-millionth part of gravity, and would be inefficient as a motor power. Moreover it remains to be proved as a matter of fact whether the surface of the equatorial ocean is really elevated by solar heat above the level of the polar seas. The superficial temperature averages 79°·8 Fahr. for the whole year, so that the amount of evaporation may be expected to exceed that of the Mediterranean, which only attains an equally high temperature at the surface during the extreme heat of summer, and falls about twenty-five degrees lower in winter. If then in spite of this smaller quantity of heat it is only by an indraught from the Atlantic that the level of the inland sea can be sustained, it may be questioned whether, taking into account evaporation, barometric pressure, floating icebergs, and other conflicting and compensating causes in the open ocean, we have sufficient data to enable us to infer in what direction a movement would be induced. Indeed it seems almost idle to be speculating upon supposed under-currents so imperceptible as not to be tested by a sounding-line, and surface flows depending upon a slope only capable of producing an accelerating force of one two-millionth part of gravity, when we have known currents flowing for thousands of miles from north to south, and south to north, which reach for hundreds of fathoms, from the surface to the bottom of deep seas, and flow so many miles a day as to render them capable of transferring in short periods of time great volumes of water of different temperatures from one part of the globe to another.

DESTROYING AND TRANSPORTING POWER OF CURRENTS.

After these preliminary remarks on the nature and causes of currents, their velocity and direction, we may next consider their action on the solid materials of the earth. We shall find that their efforts are, in many respects, strictly analogous to those of rivers. I have already treated, in the third chapter, of the manner in which currents sometimes combine with ice, in carrying mud, pebbles, and large fragments of rock to great distances. Their operations are more concealed from our view than those of rivers, but extend to wider areas, and are therefore of more geological importance.

Action of the sea on the British coast—Shetland Islands.—If we follow the eastern and southern shores of the British Islands, from our Ultima Thule in Shetland to the Land's End in Cornwall, we shall find evidence of a series of changes since the historical era, very illustrative of the kind and degree of force exerted by tides and currents co-operating with the waves of the sea. In this survey we shall have an opportunity of tracing their joint power on islands, promontories, bays, and estuaries; on bold, lofty cliffs, as well as on low shores; and on every description of rock and soil, from granite to blown sand.

The northernmost group of the British Islands, the Shetland, are composed of a great variety of rocks, including granite, gneiss, mica-slate, serpentine, greenstone, and many others, with some secondary rocks, chiefly sandstone and conglomerate. These islands are exposed continually to the uncontrolled violence of the Atlantic, for no land intervenes between their western shores and America. The prevalence, therefore, of strong westerly gales causes the waves to be sometimes driven with tremendous force upon the coast, while there is also a current setting from the north. The spray of the sea aids the decomposition of the rocks, and prepares them to be breached by the mechanical force of the waves. Steep cliffs are hollowed out into deep caves and lofty arches; and almost every promontory ends in a cluster of rock, imitating the forms of columns, pinnacles, and obelisks.

Drifting of large masses of rock.—Modern observations show that the reduction of continuous tracts to such insular masses is a process in which nature is still actively engaged. 'The Isle of Stenness,' says Dr. Hibbert, 'presents a scene of unequalled desolation. In stormy winters, huge blocks of stones are overturned, or are removed from their native beds, and hurried up a slight acclivity to a distance almost incredible. In the winter of 1802, a tabular-shaped mass, eight feet two inches by seven feet, and five feet one inch thick, was dislodged from its bed, and removed to a distance of from eighty to ninety feet. I measured the recent bed from which a block had been carried away the preceding winter (A.D. 1818), and found it to be seventeen feet and a half by seven feet, and the depth two feet eight inches. The removed mass had been borne to a distance of thirty feet, when it was shivered into thirteen or more lesser fragments, some of which were carried still farther, from 30 to 120 feet. A block, nine feet two inches by six feet and a half, and four feet thick, was hurried up the acclivity to a distance of 510 feet.' *

At Northmavine, also, angular blocks of stone, some of which are represented in the annexed figure 46, have been removed in a similar manner to considerable distances by the waves of the sea.

Effects of lightning.—In addition to numerous examples of masses detached and driven by the waves, tides, and currents from their place, some remarkable effects of lightning are recorded in these isles. At Funzie, in Fetlar, about the middle of the last century, a rock of mica-schist, 105 feet long, ten feet broad, and in some places four feet thick, was in an instant torn by a flash of lightning from its bed, broken into three large and several smaller fragments. One of these, twenty-six feet long, ten feet broad, and four feet thick, was simply turned over. The second, which was twenty-eight feet long, seventeen broad, and five feet in thickness, was hurled across a high point to the distance of 50 yards. Another broken mass, about forty feet long, was thrown still

* Description of Shetland Isles, p. 527. Edin. 1822, to which work I am indebted for the following representations of rocks in the Shetland Isles.

farther, but in the same direction, quite into the sea. There were also many smaller fragments scattered up and down.*

When we thus see electricity co-operating with the violent movements of the ocean in heaping up piles of shattered rocks on dry land and beneath the waters, we cannot but admit that a region which shall be the theatre, for myriads of ages, of the action of such disturbing causes, might present, at some future period, if upraised far above the bosom of the deep, a scene of havoc and ruin that may compare with any now found by the geologist on the surface of our continents.

Fig. 46.

Stony fragments drifted by the sea. Northmavine, Shetland.

In some of the Shetland Isles, as on the west of Meikle Roe, dikes, or veins of soft granite, have mouldered away; while the matrix in which they were enclosed, being of the same substance, but of a firmer texture, has remained unaltered. Thus, long narrow ravines, sometimes twenty feet wide, are laid open, and often give access to the waves. After describing some huge cavernous apertures into which the sea flows for 250 feet in Loeness, Dr. Hibbert, writing in 1822, enumerates other ravages of the ocean. 'A mass of rock, the average dimensions of which may perhaps be rated at twelve or thirteen feet square, and four and a half or five in thickness, was first moved from its bed, about fifty years ago, to a distance of thirty feet, and has since been twice turned over.'

Passage forced by the sea through porphyritic rocks.—'But

* Dr. Hibbert, from MSS. of Rev. George Low, of Fetlar.

the most sublime scene is where a mural pile of porphyry, escaping the process of disintegration that is devastating the coast, appears to have been left as a sort of rampart against the inroads of the ocean;—the Atlantic, when provoked by wintry gales, batters against it with all the force of real artillery—the waves having, in their repeated assaults, forced themselves an entrance. This breach, named the Grind of the Navir (fig. 47), is widened every winter by the over-

Fig. 47.

Grind of the Navir—passage forced by the sea through rocks of hard porphyry.

whelming surge that, finding a passage through it, separates large stones from its sides, and forces them to a distance of no less than 180 feet. In two or three spots, the fragments which have been detached are brought together in immense heaps, that appear as an accumulation of cubical masses, the product of some quarry.' *

It is evident from this example, that although the greater indestructibility of some rocks may enable them to withstand, for a longer time, the action of the elements, yet they cannot permanently resist. There are localities in Shetland in which rocks of almost every variety of mineral composition are suffering disintegration; thus the sea makes great inroads on the clay slate of Fitfel Head, on the serpentine

* Hibbert, p. 528.

of the Vord Hill in Fetlar, and on the mica-schist of the Bay of Trieste, on the east coast of the same island, which decomposes into angular blocks. The quartz rock on the

Fig. 48.

Granitic rocks named the Drongs, between Papa Stour and Hillswick Ness.

east of Walls, and the gneiss and mica-schist of Garthness, suffer the same fate.

Destruction of islands.—Such devastation cannot be incessantly committed for thousands of years without dividing

Fig. 49.

Granitic rocks to the south of Hillswick Ness, Shetland.

islands, until they become at last mere clusters of rocks, the last shreds of masses once continuous. To this state many appear to have been reduced, and innumerable fantastic

forms are assumed by rocks adjoining these islands, to which the name of Drongs is applied, as it is to those of similar shape in Faroe.*

The granitic rocks (fig. 48) between Papa Stour and Hillswick Ness afford an example. A still more singular cluster of rocks is seen to the south of Hillswick Ness (fig. 49), which presents a variety of forms as viewed from different points, and has often been likened to a small fleet of vessels with spread sails.† We may imagine that in the course of time Hillswick Ness itself may present a similar wreck, from the unequal decomposition of the rocks whereof it is composed, consisting of gneiss and mica-schist traversed in all directions by veins of felspar-porphyry.

Midway between the groups of Shetland and Orkney is Fair Island, said to be composed of sandstone with high perpendicular cliffs. The current runs with such velocity, that during a calm, and when there is no swell, the rocks on its shores are white with the foam of the sea driven against them. The Orkneys, if carefully examined, would probably illustrate our present topic as much as the Shetland group. The north-east promontory of Sanda, one of these islands, has been cut off in modern times by the sea, so that it became what is now called Start Island, where a lighthouse was erected in 1807, since which time the new strait has grown broader.

East coast of Scotland.—To pass over to the mainland of Scotland, we find that in Inverness-shire there have been inroads of the sea at Fort George, and others in Morayshire, which have swept away the old town of Findhorn. On the coast of Kincardineshire, an illustration was afforded, at the close of the last century, of the effect of promontories in protecting a line of low shore. The village of Mathers, two miles south of Johnshaven, was built on an ancient shingle beach, protected by a projecting ledge of limestone rock. This was quarried for lime to such an extent that the sea broke through, and in 1795 carried away the whole village in one night, and penetrated 150 yards inland, where it has maintained its ground ever since, the new village having

* Hibbert, p. 519. † Ibid.

been built farther inland on the new shore. In the Bay of Montrose, we find the North Esk and the South Esk rivers pouring annually into the sea large quantities of sand and pebbles; yet they have formed no deltas, for the waves, aided by the current, setting across their mouths, sweep away all the materials. Considerable beds of shingle, brought down by the North Esk, are seen along the beach.

Proceeding southwards, we learn that at Arbroath, in Forfarshire, which stands on a rock of red sandstone, gardens and houses have been carried away since the commencement of the present century by encroachments of the sea. In the same county, at Button Ness, it had become necessary, before 1828, to remove the lighthouses at the mouth of the estuary of the Tay, which were built on a tract of blown sand, the sea having encroached for three-quarters of a mile.

Estuary of the Tay—Bell-Rock Lighthouse.—The combined power which waves and currents can exert in *estuaries* (a term which I confine to bays entered both by rivers and the tides of the sea) was remarkably exhibited during the building of the Bell-Rock Lighthouse, off the mouth of the Tay. The Bell Rock is a sunken reef, consisting of red sandstone, being from twelve to sixteen feet under the surface at high water, and about twelve miles from the mainland. At the distance of 100 yards, there is a depth, in all directions, of two or three fathoms at low water. In 1807, during the erection of the lighthouse, six large blocks of granite, which had been landed on the reef, were removed by the force of the sea, and thrown over a rising ledge to the distance of twelve or fifteen paces; and an anchor, weighing about 22 cwt., was thrown up upon the rock.* Mr. Stevenson informs us, moreover, that drift stones, measuring upwards of thirty cubic feet, or more than two tons' weight, have, during storms, been often cast upon the rock from the deep water.†

Coast of Fife and Firth of Forth.—On the coast of Fife, at St. Andrew's, a tract of land, said to have intervened between the castle of Cardinal Beaton and the sea, has been entirely

* Account of Erection of Bell-Rock Lighthouse, p. 163.

† Ed. Phil. Journ. vol. iii. p. 54. 1820.

swept away, as were the last remains of the Priory of Crail, in 1803. On both sides of the Firth of Forth, land has been consumed; at North Berwick in particular, and at Newhaven, where an arsenal and dock, built in the reign of James IV., in the fifteenth century, has been overflowed.

East coast of England.—If we now proceed to the English coast, we find records of numerous lands having been destroyed in Northumberland, as those near Bamborough and Holy Island, and at Tynemouth Castle, which now overhangs the sea, although formerly separated from it by a strip of land. At Hartlepool, and several other parts of the coast of Durham composed of magnesian limestone, the sea has made considerable inroads.

Coast of Yorkshire.—Almost the whole coast of Yorkshire, from the mouth of the Tees to that of the Humber, is in a state of gradual dilapidation. That part of the cliffs which consists of lias, the oolite series, and chalk, decays slowly. These rocks present abrupt and naked precipices, often 300 feet in height; and it is only at a few points that the grassy covering of the sloping talus marks a temporary relaxation of the erosive action of the sea. The chalk cliffs are worn into caves and needles in the projecting headland of Flamborough, where they are decomposed by the sea spray, and slowly crumble away. But the waste is most rapid between that promontory and Spurn Point, or the coast of Holderness, as it is called, a tract consisting of beds of clay, gravel, sand, and chalk rubble. The argillaceous beds which are irregularly intermixed cause many springs to be thrown out, and this facilitates the undermining process, the waves beating against them, and a strong current setting chiefly from the north. The wasteful action is very conspicuous at Dimlington Height, the loftiest point in Holderness, where the beacon stands on a cliff 146 feet above high water, composed of clay, with pebbles scattered through it.* 'For many years,' says Professor Phillips, 'the rate at which the cliffs recede from Bridlington to Spurn, a distance of thirty-six miles, has been found by measurement to equal on an average two and a quarter yards annually, which upon thirty-six miles of coast

* Phillips's Geology of Yorkshire, p. 61.

would amount to about thirty acres a year. At this rate, the coast, the mean height of which above the sea is about forty feet, has lost one mile in breadth since the Norman Conquest, and more than two miles since the occupation of York (Eboracum) by the Romans.'* The extent of this denudation, as estimated by the number of cubic feet of matter removed annually, will be again spoken of in Chapter XXII.

In the old maps of Yorkshire, we find spots, now sand-banks in the sea, marked as the ancient sites of the towns and villages of Auburn, Hartburn, and Hyde. 'Of Hyde,' says Pennant, 'only the tradition is left; and near the village of Hornsea, a street called Hornsea Beck has long since been swallowed.'† Owthorne and its church have also been in great part destroyed, and the village of Kilnsea; but these villages have been rebuilt farther inland. The annual rate of encroachment at Owthorne for several years preceding 1830 is stated to have averaged about four yards. Not unreasonable fears are entertained that at some future time the Spurn Point will become an island, and that the ocean, entering into the estuary of the Humber, will cause great devastation.‡ Pennant, after speaking of the silting up of some ancient ports in that estuary, observes, 'But, in return, the sea has made most ample reprisals; the site, and even the very names of several places, once towns of note upon the Humber, are now only recorded in history. Ravensper was at one time a rival to Hull (Madox, Ant. Exch. i. 422), and a port so very considerable in 1332, that Edward Baliol and the confederated English barons sailed from hence to invade Scotland; and Henry IV., in 1399, made choice of this port to land at, to effect the deposal of Richard II.; yet the whole of this has long since been devoured by the merciless ocean; extensive sands, dry at low water, are to be seen in their stead.' §

Pennant describes Spurn Head as a promontory in the form

* Rivers, Mountains, and Sea-Coast of Yorkshire, p. 122. 1853, London.

† Arctic Zoology, vol. i. p. 10. Introduction.

‡ Phillips's Geology of Yorkshire, p. 60.

§ Arctic Zoology, vol. i. p. 13. Introduction.

of a sickle, and says the land, for some miles to the north, was 'perpetually preyed on by the fury of the German Sea, which devours whole acres at a time, and exposes on the shores considerable quantities of beautiful amber.'

Lincolnshire.—The maritime district of Lincolnshire consists chiefly of lands that lie below the level of the sea, being protected by embankments. Some of the fens were embanked and drained by the Romans; but after their departure the sea returned, and large tracts were covered with beds of silt containing marine shells, now again converted into productive lands. Many dreadful catastrophes by incursions of the sea are recorded, whereby several parishes have been at different times overwhelmed.

Norfolk.—The decay of the cliffs of Norfolk and Suffolk is incessant. At Hunstanton, on the north, the undermining of the lower arenaceous beds at the foot of the cliff, causes masses of red and white chalk to be precipitated from above. Between Hunstanton and Weybourne, low hills, or dunes, of blown sand, are formed along the shore, from fifty to sixty feet high. They are composed of dry sand, bound in a compact mass by the long creeping roots of the plant called Marram (*Arundo arenaria*). Such is the present set of the tides that the harbours of Clay, Wells, and other places, are securely defended by these barriers; affording a clear proof that it is not the strength of the material at particular points that determines whether the sea shall be progressive or stationary, but the general contour of the coast.

The waves constantly undermine the low chalk cliffs, covered with sand and clay, between Weybourne and Sheringham, a certain portion of them being annually removed. At the latter town I ascertained, in 1829, some facts which throw light on the rate at which the sea gains upon the land. It was computed, when the present inn was built, in 1805, that it would require seventy years for the sea to reach the spot: the mean loss of land being calculated, from previous observations, to be somewhat less than one yard annually. The distance between the house and the sea was fifty yards; but no allowance was made for the slope of the ground being *from* the sea, in consequence of which the waste was natu-

rally accelerated every year, as the cliff grew lower, there being at each succeeding period less matter to remove when portions of equal area fell down. Between the years 1824 and 1829, no less than seventeen yards were swept away, and only a small garden was then left between the building and the sea. There was, in 1829, a depth of twenty feet (sufficient to float a frigate) at one point in the harbour of that port, where, only forty-eight years before, there stood a cliff fifty feet high, with houses upon it! If once in half a century an equal amount of change were produced suddenly by the momentary shock of an earthquake, history would be filled with records of such wonderful revolutions of the earth's surface; but if the conversion of high land into deep sea be gradual, it excites only local attention. The flag-staff of the Preventive Service station, on the south side of this harbour, was thrice removed inland between the years 1814 and 1829, in consequence of the advance of the sea.

Farther to the south we find cliffs, composed, like those of Holderness before mentioned, of alternating strata of blue clay, gravel, loam, and fine sand. Although they sometimes exceed 300 feet in height, the havoc made on the coast is most formidable. The whole site of ancient Cromer now forms part of the German Ocean, the inhabitants having gradually retreated inland to their present situation, whence the sea still threatens to dislodge them. In the winter of 1825, a fallen mass was precipitated from near the lighthouse, which covered twelve acres, extending far into the sea, the cliffs being 250 feet in height.* The undermining by springs has sometimes caused large portions of the upper part of the cliffs, with houses still standing upon them, to give way, so that it is impossible, by erecting breakwaters at the base of the cliffs, permanently to ward off the danger. Mr. Redman states that during the twenty-three years which elapsed between the Ordnance Survey of 1838 and the year 1861, a portion of the cliff, composed of sand and clay, between Cromer and Mundesley, receded 330 feet, amounting to a mean annual waste of fourteen feet; and the cliff at

* Taylor's Geology of East Norfolk, p. 32.

Happisburgh has, according to his estimate, wasted at the rate of about seven feet a year for sixty years preceding 1864.*

On the same coast, says Mr. R. C. Taylor, the ancient villages of Shipden, Wimpwell, and Eccles have disappeared; several manors and large portions of neighbouring parishes having, piece after piece, been swallowed up; nor has there been any intermission, from time immemorial, in the ravages of the sea along a line of coast twenty miles in length, on

Fig. 50.

Tower of the buried Church of Eccles, Norfolk, A.D. 1839.

The inland slope of the hills of blown sand is shown in this view, with the Lighthouse of Hasborough, N.W. of the tower, in the distance.

which these places stood.† Of Eccles, however, a monument still remains in the ruined tower of the old church. So early as 1605 the inhabitants petitioned James I. for a reduction of taxes, as 300 acres of land, and all their houses, save fourteen, had then been destroyed by the sea. Not one-half that number of acres now remains in the parish, and hills of blown sand, called 'Marrams' from the plant by which they are overgrown, now occupy the site of the houses,

* East Coast between Thames and Wash, J. B. Redman, C.E., Proc. Inst. Civil Engineers, vol. xxiii. pp. 31–33, 1864.

† Taylor's Geology of East Norfolk, p. 32.

which were still extant in 1605. When I visited the spot in 1839, I found the tower of the church half buried in the dunes of sand, as represented in the drawing (fig. 50), and twenty-three years afterwards my friend the Rev. S. W. King made a sketch from nearly the same spot, which is given in fig. 51. In the interval the sand dunes, which are always moving inland, had considerably altered their position in reference to the tower, which after the storm of 1862 was

Fig. 51.

Eccles Tower as it appeared after the storm of November 1862, from a drawing by Rev. S. W. King, taken from nearly the same position as fig. 50.

seen as represented in fig. 51, on the sea-side, the waves having washed the foundations of the edifice.* The level of the base of the tower, and of the ruins of the nave and chancel of the church (see fig. 51) has now such a relation to high-water mark, that Mr. King naturally suggests that there must have been a subsidence of this part of the coast since the church was built. The precise date of its erection is unknown, but the upper or octagonal part of the tower is supposed to date from the 16th century, and this addition

* Mr. Redman has given us a view of Eccles Tower as seen by him in 1861, when it was nearly as much on the seaward side of the dunes as in 1862.

would not have been made at that period had the site been considered as in danger from the encroachments of the sea.

Observations on the level of the foundations of buildings now within reach of the tide may hereafter lead us to an exact estimate of a change of level if there be one in progress, although, antecedently to experience, we might have anticipated that a wasting coast was less favourable than any other for ascertaining whether the land was rising, sinking, or stationary. As the tide rises eight feet at Lowestoft, and sixteen at Cromer, it becomes a question whether in the course of four or five centuries its mean level at any given point on this eastern coast may vary sufficiently to explain the present position of the ruined church at Eccles relatively to high-water mark, but I am not aware that we have any recorded data for confirming or invalidating such an hypothesis.

M. E. de Beaumont has suggested that sand-dunes in Holland and other countries may serve as natural chronometers, by which the date of the existing continents may be ascertained. The sands, he says, are continually blown inland by the force of the winds, and by observing the rate of their march we may calculate the period when the movement commenced.* But the example just given will satisfy every geologist that we cannot ascertain the starting-point of dunes, all coasts being liable to waste, and the shores of the Low Countries in particular being not only exposed to inroads of the sea, but, as M. de Beaumont himself has well shown, having even in historical times undergone a change of level. The dunes may indeed, in some cases, be made use of as chronometers, to enable us to assign a minimum of antiquity to existing coast-lines; but this test must be applied with great caution, so variable is the rate at which the sands may advance into the interior.

Hills of blown sand, between Eccles and Winterton, have barred up and excluded the tide for many hundred years from the mouths of several small estuaries; but there are records of nine breaches, from 20 to 120 yards wide, having

* De Beaumont, Géologie Pratique, p. 218.

been made through these, by which immense damage was done to the low grounds in the interior. A few miles south of Happisburgh, also, are hills of blown sand, which extend to Yarmouth. These *dunes* afford a temporary protection to the coast, and an inland cliff about a mile long, at Winterton, shows clearly that at that point the sea must have penetrated formerly farther than at present.

Silting up of estuaries.—At Yarmouth, the sea has not advanced upon the sands in the slightest degree since the reign of Elizabeth. In the time of the Saxons, a great estuary extended as far as Norwich, which city is represented even in the thirteenth and fourteenth centuries as 'situated on the banks of an arm of the sea.' The sands whereon Yarmouth is built first became firm and habitable ground about the year 1008, from which time a line of dunes has gradually increased in height and breadth, stretching across the whole entrance of the ancient estuary, and obstructing the ingress of the tides so completely that they are only admitted by the narrow passage which the river keeps open, and which has gradually shifted several miles to the south. The ordinary tides at the river's mouth rise, at present, only to the height of three or four feet, the spring tides to about eight or nine.

By the exclusion of the sea, thousands of acres in the interior have become cultivated lands; and, exclusive of smaller pools, upwards of sixty freshwater lakes have been formed, varying in depth from fifteen to thirty feet, and in extent from one acre to twelve hundred.* The Yare, and other rivers, frequently communicate with these sheets of water; and thus they are liable to be filled up gradually with lacustrine and fluviatile deposits, and to be converted into land covered with forests. Yet it must not be imagined that the acquisition of new land fit for cultivation in Norfolk and Suffolk indicates any permanent growth of the eastern limits of our island to compensate its reiterated losses. No *delta* can form on such a shore.

In the sea immediately off Yarmouth is a great range of

* Taylor's Geology of East Norfolk, p. 10.

sand-banks parallel to the shore, the shape of which varies slowly from year to year, and often suddenly after great storms. Captain Hewitt, R.N., found in these banks, in 1836, a broad channel sixty-five feet deep, where there was only a depth of four feet during a prior survey in 1822. The sea had excavated to the depth of sixty feet in the course of fourteen years, or perhaps a shorter period. The new channel thus formed served in 1838 for the entrance of ships into Yarmouth Roads; and the magnitude of this change shows how easily a new set of the waves and currents might cause the submergence of the land gained within the ancient estuary of the Yare.

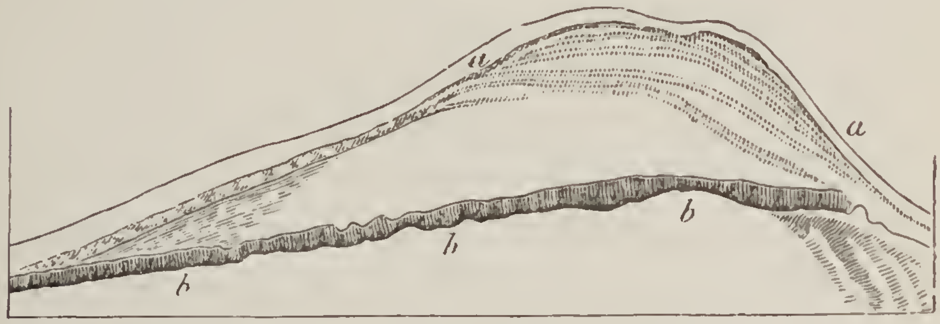
That great banks should be thrown across the mouth of estuaries on our eastern coast, where there is not a large body of river-water to maintain an open channel, is perfectly intelligible, when we bear in mind that the marine current, sweeping along the coast, is charged with the materials of wasting cliffs, and ready to form a bar anywhere the instant its course is interrupted or checked by any opposing stream. The mouth of the Yare has been, within the last five centuries, diverted about four miles to the south. In like manner it is evident that, at some remote period, the river Alde entered the sea at Aldborough, until its ancient outlet was barred up and at length transferred to a point no less than ten miles distant to the south-west. In this case, ridges of sand and shingle, like those of Lowestoft Ness, which will be described by-and-by, have been thrown up between the river and the sea; and the ancient sea-cliff is now to be seen inland. (See fig. 52.)

It may be asked why the rivers on our east coast are always deflected southwards, although the tidal current flows alternately from the south and north? The cause is to be found in the superior force of what is commonly called 'the flood tide from the north,' a tidal wave derived from the Atlantic, a small part of which passes eastward up the English Channel, and through the Straits of Dover and then northwards, while the principal body of water, moving much more rapidly in a more open sea, on the western side of Britain, first passes

the Orkneys, and then, turning, flows down between Norway and Scotland, and sweeps with great velocity along our eastern coast. It is well known that the highest tides on this coast are occasioned by a powerful north-west wind, which raises the eastern part of the Atlantic, and causes it to pour a greater volume of water into the German Ocean. This circumstance of a violent *off-shore* wind being attended with a rise of the waters, instead of a general retreat of the sea, naturally excites the wonder of the inhabitants of our coast. In many districts they look with confidence for a rich harvest of that valuable manure, the sea-weed, when the north-westerly gales prevail, and are rarely disappointed.

Coast of Suffolk.—The cliffs of Suffolk, to which we next

Fig. 52.



Map of Lowestoft Ness, Suffolk.*

a, a. The dotted lines express a series of sand and shingle, forming the extremity of the triangular space called the Ness.

b, b, b. The dark line represents the inland cliff on which the town of Lowestoft stands, between which and the sea is the Ness.

proceed, are somewhat less elevated than those of Norfolk, but composed of similar alternations of clay, sand, and gravel. From Gorleston, in Suffolk, to within a few miles north of Lowestoft, the cliffs are being slowly undermined. Near the last-mentioned town there is an inland cliff about sixty feet high, the sloping talus of which is covered with turf and heath. Between the cliff and the sea is a low flat tract of sand, called the Ness, nearly three miles long, and for the most part out of reach of the highest tides (see fig. 52). The point

* From Mr. R. C. Taylor's Mem. See Phil. Mag. Oct. 1827, p. 297.

of the Ness projects from the base of the original cliff to the distance of 660 yards. This accession of land, says Mr. Taylor, has been effected at distinct and distant intervals, by the influence of currents running between the land and a shoal called the Holm Sand, about a mile off Lowestoft. The lines of growth in the Ness are indicated by a series of concentric ridges or banks enclosing limited areas, and several of these ridges have been formed within the observation of persons now living. A rampart of heavy materials is first thrown up to an unusual altitude by some extraordinary tide attended with a violent gale. Subsequent tides extend the base of this high bank of shingle, and the interstices are then filled with sand blown from the beach. The Arundo and other sea-side plants by degrees obtain a footing; and creeping along the ridge, give solidity to the mass, and form in some cases a matted covering of turf. Meanwhile another mound is forming externally, which by the like process rises and gives protection to the first. If the sea forces its way through one of the external and incomplete mounds, the breach is soon repaired. After a while the maritime plants within the areas enclosed by these embankments are succeeded by a better species of herbage affording good pasturage, and the sands become sufficiently firm to support buildings.

Destruction of Dunwich by the sea.—Of the gradual destruction of Dunwich, once the most considerable seaport on this coast, we have many authentic records. Gardner, in his history of that borough, published in 1754, shows, by reference to documents, beginning with Doomsday Book, that the cliffs at Dunwich, Southwold, Easton, and Pakefield have been always subject to waste. At Dunwich, in particular, two tracts of land which had been taxed in the eleventh century, in the time of King Edward the Confessor, are mentioned, in the Conqueror's survey, made but a few years afterwards, as having been devoured by the sea. The losses, at a subsequent period, of a monastery,—at another of several churches,—afterwards of the old port,—then of four hundred houses at once,—of the church of St. Leonard, the high-road, town-hall, gaol, and many other buildings,

are mentioned, with the dates when they perished. It is stated that, in the sixteenth century, not one quarter of the town was left standing; yet, the inhabitants retreating inland, the name was preserved, as has been the case with many other ports, when their ancient site has been blotted out. There is, however, a church, of considerable antiquity, still standing, the last of twelve mentioned in some records. In 1740, the laying open of the churchyard of St. Nicholas and St. Francis, in the sea-cliffs, is well described by Gardner, with the coffins and skeletons exposed to view—some lying on the beach, and rocked

In cradle of the rude imperious surge.

Of these cemeteries no remains can now be seen. Ray also says, 'that ancient writings make mention of a wood a mile and a half to the east of Dunwich, the site of which must at present be so far within the sea.'* This city, once so flourishing and populous, is now a small village, with about twenty houses and one hundred inhabitants.

There is an old tradition, 'that the tailors sat in their shops at Dunwich, and saw the ships in Yarmouth Bay;' but when we consider how far the coast at Lowestoft Ness projects between these places, we cannot give credit to the tale, which, nevertheless, proves how much the inroads of the sea in times of old had prompted men of lively imagination to indulge their taste for the marvellous.

Gardner's description of the cemeteries laid open by the waves reminds us of the scene which has been so well depicted by Bewick,† and of which numerous points on the same coast might have suggested the idea. On the verge of a cliff, which the sea has undermined, are represented the unshaken tower and western end of an abbey. The eastern aisle is gone, and the pillars of the cloister are soon to follow. The waves have almost isolated the promontory, and invaded the cemetery, where they have made sport with the mortal relics, and thrown up a skull upon the beach. In the foreground is seen a broken tombstone, erected, as its legend

* Consequences of the Deluge, Phys. Theol. Discourses.

† History of British Birds, vol. ii. p. 220, ed. 1821.

tells, 'to *perpetuate* the memory'—of one whose name is obliterated, as is that of the county for which he was 'Custos Rotulorum.' A cormorant is perched on the monument, defiling it, as if to remind some moraliser, like Hamlet, of 'the base uses' to which things sacred may be turned. Had this excellent artist desired to satirize certain popular theories of geology, he might have inscribed the stone to the memory of some philosopher who taught 'the permanency of existing continents'—'the era of repose'—'the impotence of modern causes.'

The incursions of the sea at Aldborough were formerly very destructive, and this borough is known to have been once situated a quarter of a mile east of the present shore. The inhabitants continued to build farther inland, till they arrived at the extremity of their property, and then the town decayed greatly: but two sand-banks, thrown up at a short distance, now afford a temporary safeguard to the coast. Between these banks and the present shore, where the current now flows, the sea is twenty-four feet deep on the spot where the town formerly stood.

Essex.—Harwich is said to have owed its rise to the destruction of Orwell, a town which stood on the spot now called 'the west rocks,' and was overwhelmed by an inroad of the sea since the Conquest. Apprehensions have been entertained that the isthmus on which Harwich stands may at no remote period become an island, for the sea may be expected to make a breach near Lower Dovercourt, where Beacon Cliff is composed of horizontal beds of London clay containing septaria. It had wasted away considerably between the years 1829 and 1838, at both which periods I examined this coast. In that short interval several gardens and many houses had been swept into the sea, and in April 1838 a whole street was threatened with destruction. The advance of the sea is much accelerated by the traffic carried on in septaria, which are shipped off for cement as fast as they fall down upon the beach. These stones, if allowed to remain in heaps on the shore, would break the force of the waves, and retard the conversion of the peninsula into an island, an event which might be followed by the destruction

of the town of Harwich. Captain Washington, R.N., ascertained, in 1847, that Beacon Cliff, above mentioned, which is about fifty feet high, had given way at the rate of forty feet in forty-seven years, between 1709 and 1756; eighty feet between 1756 and 1804; and three hundred and fifty feet between the latter period and 1841; showing a rapidly accelerated rate of destruction.*

Among other losses it is recorded that, since the year 1807, a field called the Vicar's Field, which belonged to the living of Harwich, has been overwhelmed;† and in the year 1820 there was a considerable space between the battery at Harwich, built in the beginning of the present century, and the sea; part of the fortification had been swept away in 1829, and the rest then overhung the water.

At Walton-on-the-Naze, in the same county, the cliffs, composed of London clay, capped by the shelly sands of the crag, reach the height of about 100 feet, and are annually undermined by the waves. The old churchyard at Walton has been washed away, and the cliffs to the south are constantly disappearing.

Kent.—Isle of Sheppey.—On the coast bounding the estuary of the Thames, there are numerous examples both of the gain and loss of land. The Isle of Sheppey, which is now about six miles long by four in breadth, is composed of London clay. The cliffs on the north, which are from 100 to 200 feet high, decay rapidly, fifty acres having been lost in twenty years, between 1810 and 1830. The church at Minster, now near the coast, is said to have been in the middle of the island in 1780; and if the present rate of destruction should continue, we might calculate the period, and that not a very remote one, when the whole island will be annihilated. On the coast of the mainland, to the east of Sheppey, is Herne Bay; a place still retaining the name of a bay, although the term is no longer appropriate, as the waves and currents have swept away the ancient headlands. There was formerly a small promontory in the line of the shoals where the present

* Tidal Harbour Commissioners' First Report, 1845, p. 176.

† On the authority of Dr. Mitchell, F.G.S.

pier is built, by which the larger bay was divided into two called the Upper and Lower.*

Still farther east stands the church of Reculver, upon a cliff, about twenty-five feet high, composed of sand with some interstratified slabs of clayey sandstone. Reculver (Regulvium) was an important military station in the time of the Romans, and appears, from Leland's account, to have been, so late as Henry VIII.'s reign, nearly one mile distant from the sea. In the 'Gentleman's Magazine' there is a view of it, taken in 1781, which still represents a considerable space as inter-

Fig. 53.

View of Reculver Church, taken in the year 1781.

1. Isle of Sheppey. 2 Ancient chapel now destroyed. The cottage between this chapel and the cliff was demolished by the sea in 1782.

vening between the north wall of the churchyard and the cliff.† Some time before the year 1780, the waves had reached the site of the ancient Roman camp, or fortification, the walls of which had continued for several years after they were undermined to overhang the sea, being firmly cemented into one mass. They were eighty yards nearer the sea than the church, and they are spoken of in the 'Topographica Britannica,' in the year 1780, as having recently fallen down. In 1804, part of the churchyard with some adjoining houses was washed away, and the ancient church, with its two spires, was

* On the authority of W. Gunnel, Esq., and W. Richardson, Esq., F.G.S.

† Vol. ii. New Series, 1809, p. 801.

dismantled and abandoned as a place of worship, but kept in repair as a landmark well known to mariners. I visited the spot in June 1851, and saw human bones and part of a wooden coffin projecting from the cliff, near the top. The whole building would probably have been swept away long ere this, had not the force of the waves been checked by an artificial causeway of stones and large wooden piles driven into the sands on the beach to break the force of the waves.

Isle of Thanet.—The Isle of Thanet was, in the time of the

Fig. 54.

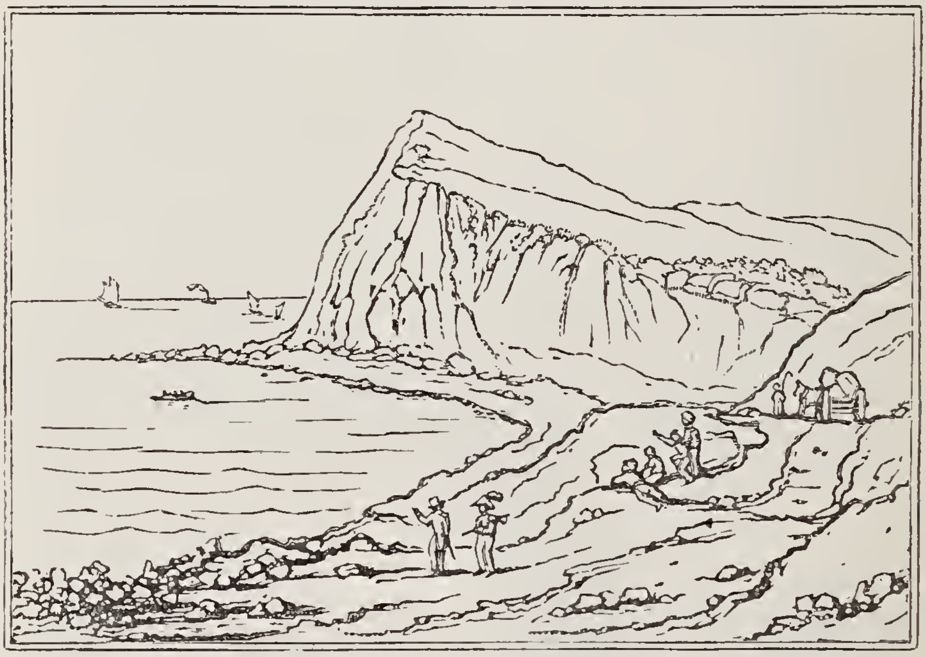
Reculver Church, in 1834.

Romans, separated from the rest of Kent by a navigable channel, through which the Roman fleets sailed on their way to and from London. Bede describes this small estuary as being, in the beginning of the eighth century, three furlongs in breadth; and it is supposed that it began to grow shallow about the period of the Norman Conquest. It was so far silted up in the year 1845 that an Act was obtained to build a bridge across it; and it has since become marsh land with small streams running through it. On the coast, Bedlam

Farm, belonging to the hospital of that name, lost eight acres in the twenty years preceding 1830, the land being composed of chalk from forty to fifty feet above the level of the sea. It has been computed, that the average waste of the cliff between the North Foreland and the Reculvers, a distance of about eleven miles, is not less than two feet per annum. The chalk cliffs on the south of Thanet, between Ramsgate and Pegwell Bay, had on an average lost three feet per annum during the ten years preceding 1830.

Goodwin Sands.—The Goodwin Sands lie opposite this part of the Kentish coast. They are about ten miles in length, and are in some parts three, and in others seven, miles dis-

Fig. 55.



Shakspeare's Cliff in 1836, seen from the north-east.

tant from the shore; and, for a certain space, are laid bare at low water. That they are a remnant of land, and not 'a mere accumulation of sea sand,' as Rennell imagined,* may be presumed from the fact that, when the erection of a lighthouse on this shoal was in contemplation by the Trinity Board in the year 1817, it was found, by borings, that the bank consisted of fifteen feet of sand, resting on blue clay; and, by subsequent borings, the subjacent chalk has been reached. An obscure tradition has come down to us, that the estates of Earl Goodwin, the father of Harold, who died in the year 1053, were situated here, and some have

* Geol. of Herod. vol. ii. p. 326.

conjectured that they were overwhelmed by the flood mentioned in the Saxon Chronicle, *sub anno* 1099. The last remains of an island, Consisting, like Sheppey, of clay, may perhaps have been carried away about that time.

There are other records of waste in the county of Kent, as at Deal; and at Dover, where Shakspeare's Cliff, composed entirely of chalk, has suffered greatly, and continually diminishes in height, the slope of the hill being towards the land. (See fig. 55.) There was an immense landslip from this cliff in 1810, by which Dover was shaken as if by an earthquake, and a still greater one in 1772.* We may suppose, therefore, that the view from the top of the precipice in the year 1600, when the tragedy of 'King Lear' was written, was more 'fearful and dizzy' than it is now. The best antiquarian authorities are agreed that Dover Harbour was formerly an estuary, the sea flowing up a valley between the chalk hills. The remains found in different excavations confirm the description of the spot given by Cæsar and Antoninus, and there is clear historical evidence to prove that at an early period there was no shingle at all at Dover.†

Straits of Dover.—In proceeding from the northern parts of the German Ocean towards the Straits of Dover, the water becomes gradually more shallow, so that in the distance of about two hundred leagues, we pass from a depth of 120 fathoms to that of 58, 38, 18, and at one point near the middle of the Channel even less than 2 fathoms. The shallowest part follows a line drawn between Romney Marsh and Boulogne. From this point the English Channel again deepens progressively as we proceed westward, so that the Straits of Dover may be said to part two seas.‡

Whether England was formerly united to France has often been a favourite subject of speculation. So early as 1605 our countryman Verstegan, in his 'Antiquities of the English Nation,' observed that many preceding writers had maintained this opinion, but without supporting it by any weighty reasons. He accordingly endeavours himself to confirm it by

* Dodsley's Ann. Regist. 1772.

† See J. B. Redman on Changes of S.E. Coast of England, Proceed. Instit. Civil Engin. vol. xi. 1851, 1852.

‡ Stevenson, Ed. Phil. Journ. No. v. p. 45, and Dr. Fitton, Geol. Trans. 2d series, vol. iv. plate 9.

various arguments, the principal of which are, first, the proximity and identity of the composition of the opposite cliffs and shores of Albion and Gallia, which, whether flat and sandy, or steep and chalky, correspond exactly with each other; secondly, the occurrence of a submarine ridge, called 'Our Lady's Sand,' extending from shore to shore at no great depth, and which from its composition appears to be the original basis of the isthmus; thirdly, the identity of the noxious animals in France and England, which could neither have swum across, nor have been introduced by man. Thus no one, he says, would have imported wolves, therefore 'these wicked beasts did of themselves pass over.' He supposes the ancient isthmus to have been about six English miles in breadth, composed entirely of chalk and flint, and in some places of no great height above the sea-level. The operation of the waves and tides, he says, would have been more powerful when the straits were narrower, and even now they are destroying cliffs composed of similar materials. He suggests the possible co-operation of earthquakes; and when we consider how many submarine forests skirt the southern and eastern shores of England, and that there are raised beaches at many points above the sea-level, containing fossil shells of recent species, it seems reasonable to suppose that such upward and downward movements, taking place perhaps as slowly as those now in progress in Sweden and Greenland, may have greatly assisted the denuding force of 'the ocean stream,' *Ποταμοῖο μέγα σθένος Ὠκεανοῖο.*

Folkestone.—At Folkestone the sea undermines the chalk and subjacent strata. About the year 1716 there was a remarkable sinking of a tract of land near the sea, so that houses became visible from certain points at sea, and from particular spots on the sea cliffs, from whence they could not be seen previously. In the description of this subsidence in the Phil. Trans. 1716, it is said, 'that the land consisted of a solid stony mass (chalk), resting on wet clay (gault), so that it slid forwards towards the sea, just as a ship is launched on tallowed planks.' It is also stated, that within the memory of persons then living, the cliff there had been washed away to the extent of ten rods.

Encroachments of the sea at Hythe are also on record; but between this point and Rye there has been a gain of land within the times of history; the rich level tract called Romney Marsh, or Dungeness, about ten miles in width and five in breadth, and formed of silt, having received great accession. Mr. Redman has cited numerous old charts and trustworthy authorities to prove that the average annual increase of the promontory amounted for two centuries, previous to 1844, to nearly six yards. Its progress, however, has fluctuated during that period; for between 1689 and 1794, a term of 105 years, the rate was as much as $8\frac{1}{4}$ yards per annum. He observes 'that this great accumulation, commonly called Romney Marsh, is composed for a distance of about two miles of undulating ridges marking the periodical accessions made to the coast, like the rings of growth in timber.'* It is ascertained that the shingle is derived from the westward. Whether the pebbles are stopped by the meeting of the tide from the north flowing through the Straits of Dover, with that which comes up the Channel from the west, as was formerly held, or by the check given to the tidal current by the waters of the Rother, as some maintain, is still a disputed question. There is, however, no doubt that since the Point of Dungeness has advanced, forming a great natural groin, it intercepts the shingle which formerly travelled eastward and was accumulated by artificial groins at Hythe. The martello towers erected on the low coast S. and S.W. of Hythe must ere long perish, as Mr. Mackeson has pointed out to me, for want of a supply of protecting shingle. At Dymchurch the towers numbered 26, 27, have already been removed, their destruction being threatened by the advancing tide. The town of Winchelsea, situated to the south of Romney Marsh, was destroyed in the reign of Edward I., the mouth of the Rother stopped up, and the river diverted into another channel. In its old bed, an ancient vessel, apparently a Dutch merchantman, was found about the year 1824. It was built entirely of oak, and much blackened.† Large quantities of hazel-nuts, peat, and wood are found in digging in Romney Marsh.

* Redman, Proc. Civil Engin. vol. xi. p. 169.

† Edin. Journ. of Science, No. xix. p. 56.

South coast of England.—Westward of Hastings, or of St. Leonard's, the shore-line has been giving way as far as Pevensey Bay, where formerly there existed a haven now entirely blocked up by shingle. The waste has amounted for a series of years to seven feet per annum in some places, and several martello towers had in consequence, before 1851, been removed by the Ordnance.* At the promontory of Beachy Head a mass of chalk, three hundred feet in length, and from seventy to eighty in breadth, fell in the year 1813 with a tremendous crash; and similar slips have since been frequent.†

About a mile to the west of the town of Newhaven, the remains of an ancient entrenchment are seen on the brow of Castle Hill. This earthwork, supposed to be British, was evidently once of considerable extent and of an oval form, but the greater part has been cut away by the sea. The cliffs, which are undermined here, are high; more than one hundred feet of chalk being covered by tertiary clay and sand, from sixty to seventy feet in thickness. In a few centuries the last vestiges of the Woolwich Beds or plastic clay formation on the southern borders of the chalk of the South Downs on this coast will probably be annihilated, and future geologists will learn, from historical documents only, the ancient geographical boundaries of this group of strata in that direction. On the opposite side of the estuary of the Ouse, on the east of Newhaven harbour, a bed of shingle, composed of chalk flints derived from the waste of the adjoining cliffs, had accumulated at Seaford for several centuries. In the great storm of November 1824, this bank was entirely swept away, and the town of Seaford inundated. Another great beach of shingle is now forming from fresh materials.

The whole coast of Sussex has been incessantly encroached upon by the sea from time immemorial; besides the camp at Newhaven, two ancient earthworks of unknown date, one near Seaford, and the other near Eastbourne, have been partially destroyed by the encroachments of the sea. Although sudden inundations only, which overwhelmed fertile or inhabited tracts, are noticed in history, the records attest an extraor-

* Redman, as cited, p. 315.

† Webster, Geol. Trans. vol. ii. p. 192, 1st series.

dinary amount of loss. During a period of no more than eighty years, there are notices of about *twenty* inroads, in which tracts of land of from twenty to *four hundred acres* in extent were overwhelmed at once, the value of the tithes being mentioned in the Taxatio Ecclesiastica.* In the reign of Elizabeth, the town of Brighton was situated on that tract where the chain pier now extends into the sea. In the year 1665 twenty-two tenements had been destroyed under the cliff. At that period there still remained under the cliff 113 tenements, the whole of which were overwhelmed in 1703 and 1705. No traces of the ancient town are now perceptible, yet there is evidence that the sea has merely resumed its ancient position at the base of the cliffs, the site of the old town having been nothing more than a beach abandoned by the ocean for ages.

Hampshire.—Isle of Wight.—It would be endless to allude to all the localities on the Sussex and Hampshire coasts where the land has given way; but I may point out the relation which the geological structure of the Isle of Wight bears to its present shape, as attesting that the coast owes its outline to the continued action of the sea. Through the middle of the island runs a high ridge of chalk strata, in a vertical position, and in a direction east and west. This chalk forms the projecting promontory of Culver Cliff on the east, and of the Needles on the west; while Sandown Bay on the one side, and Compton Bay on the other, have been hollowed out of the softer sands and argillaceous strata, which are inferior, in geological position, to the chalk.

The same phenomena are repeated in the Isle of Purbeck, where the line of vertical chalk forms the projecting promontory of Handfast Point; and Swanage Bay marks the deep excavation made by the waves in the softer strata, corresponding to those of Sandown Bay.

Hurst Castle Bank—progressive motion of sea beaches.—Although the loose pebbles and grains of sand composing any given line of sea beach are carried sometimes one way, sometimes another, they have, nevertheless, an ultimate

* Mantell, Geology of Sussex, p. 293.

motion in one particular direction.* Their progress, for example, on the south coast of England, is from west to east, which is owing partly to the action of the waves driven eastwards by the prevailing wind, and partly to the current, or the motion of the general body of water caused by the tides and winds. The force of the waves gives motion to pebbles which the velocity of the currents alone would be unable to carry forwards; but as the pebbles are finally reduced to sand or mud, by continual attrition, they are brought within the influence of a current; and this cause must determine the course which the main body of matter derived from wasting cliffs will eventually take.

It appears, from the observations of Mr. Palmer and others, that if a pier or groin be erected anywhere on our southern or south-eastern coast to stop the progress of the beach, a heap of shingle soon collects on the western side of such artificial barriers. The pebbles continue to accumulate till they rise as high as the pier or groin, after which they pour over in great numbers during heavy gales.†

The western entrance of the Solent, a channel dividing the Isle of Wight from the mainland, is crossed for more than two-thirds of its width by the shingle-bank of Hurst Castle, which is about two miles long, seventy yards broad, and twelve feet high, presenting an inclined plane to the west. This singular bar consists of a bed of rounded chalk flints, resting on a submarine argillaceous base. The flints and a few other pebbles, intermixed, are derived from the waste of Hordwell, and other cliffs to the westward, where tertiary strata, capped with a covering of broken chalk flints, from five to fifty feet thick, are rapidly undermined. In the great storm of November 1824, this bank of shingle was moved bodily forwards for forty yards towards the north-east; and certain piles, which served to mark the boundaries of two manors, were found after the storm on the opposite side of the bar. At the same time many acres of pasture land

* See Palmer on Shingle Beaches, Phil. Trans. 1834, p. 568.

† Groins are formed of piles and wooden planks, or of faggots staked down; and are used either to break the force of the waves, or to retain the beach.

were covered by shingle, on the farm of Westover, near Lymington. But the bar was soon restored to its old position by pebbles drifted from the west; and it appears from ancient maps that it has preserved the same general outline and position for centuries.*

Mr. Austen remarks that, as a general rule, it is only when high tides concur with a gale of wind, that the sea reaches the base of cliffs so as to undermine them. But the waves are perpetually employed in abrading and fashioning the materials already strewed over the beach. Much of the gravel and shingle is always travelling up and down, between high-water mark and a slight depth below the level of the lowest tides, and occasionally the materials are swept away and carried into deeper water. Owing to these movements, every portion of our southern coast may be seen at one time or other in the condition of bare rock. Yet other beds of sand and shingle soon collect, and, although composed of new materials, invariably exhibit on the same spots precisely similar characters.†

The cliffs between Hurst Shingle Bar and Christchurch are undermined continually, the sea having often encroached for a series of years at the rate of a yard annually. Within the memory of persons now living, it has been necessary thrice to remove the coast-road farther inland. The tradition, therefore, is probably true, that the church of Hordwell was once in the middle of that parish, although now (1830) very near the sea. The promontory of Christchurch (Hengistbury) Head gives way slowly. It is the only point between Lymington and Poole Harbour, in Dorsetshire, where any hard stony masses appear in the cliffs. Five layers of large ferruginous concretions, somewhat like the septaria of the London clay, have occasioned a resistance at this point, to which we may ascribe this headland. In the meantime, the waves have cut deeply into the soft sands and loam of Poole Bay; and after severe frosts, great landslips take place, which by degrees become enlarged into narrow ravines, or chines, as they are called, with vertical sides. One of these

* Redman, as cited, p. 315.

† Rob. A. C. Godwin-Austen on the Valley of the English Channel, Quart. Journ. G. S. vol. vi. p. 72.

chines, near Boscomb, has been deepened twenty feet within a few years (1830). At the head of each there is a spring, the waters of which have been chiefly instrumental in producing these narrow excavations, which are sometimes from 100 to 150 feet deep.

Isle of Portland.—The peninsulas of Purbeck and Portland are continually wasting away. In the latter, the soft argillaceous substratum (Kimmeridge clay) hastens the dilapidation of the superincumbent mass of limestone.

In 1665 the cliffs adjoining the principal quarries in Portland gave way to the extent of one hundred yards, and fell into the sea; and in December 1734, a slide to the extent of 150 yards occurred on the east side of the isle. But a much more memorable occurrence of this nature, in 1792, occasioned probably by the undermining of the cliffs, is thus described in Hutchin's History of Dorsetshire:—'Early in the morning the road was observed to crack; this continued increasing, and before two o'clock the ground had sunk several feet, and was in one continued motion, but attended with no other noise than what was occasioned by the separation of the roots and brambles, and now and then a falling rock. At night it seemed to stop a little, but soon moved again; and, before morning, the ground from the top of the cliff to the water-side had sunk in some places fifty feet perpendicularly. The extent of ground that moved was about *a mile and a quarter* from north to south, and 600 yards from east to west.'

Formation of the Chesil Bank.—Portland is connected with the mainland by the Chesil Bank, a ridge of shingle about fifteen miles long, the first part of which, near Portland, for a length of about two miles, has the sea on each side of it. It then continues seven miles farther in a north-westerly direction as far as Abbotsbury, sloping steeply on the one side towards the sea, and on the other towards a narrow channel called the Fleet, which may be regarded as an estuary the waters of which are brackish. It then stretches for five miles farther as a pebbly beach thrown against the coast of Dorsetshire.

The pebbles forming this immense barrier are chiefly

siliceous, all loosely thrown together, and rising to the height of from twenty to thirty feet above the ordinary high-water mark; and forty feet at the south-eastern end, which is nearest the Isle of Portland, where the pebbles are largest. Here its width is about 600 feet, which diminishes to about 500 at Abbotsbury.

That part of the bar which attaches Portland to the main-land rests on Kimmeridge clay, which is sometimes exposed to view during storms. The clay may have formed a shoal, and the set of the tides in the narrow channel may have arrested the course of the pebbles, which are always coming from the west. It is a singular fact that, throughout the Chesil Bank, the pebbles increase gradually in size as we proceed south-eastward, or as we go farther from the quarter which supplied them. Had the case been reversed, we should naturally have attributed the circumstance to the constant wearing down of the pebbles by friction, the beach along which they are rolled being seventeen miles in length. But the true explanation of the phenomenon is doubtless this: the strongest currents or movements of the sea during storms, when a gale from the south-west co-operates with the tide, act with greater power in the more open channel or farthest from the head of the bay; within the bay the land affords more shelter from the wind and waves. In other words, the force of the sea increases southwards, and as the direction of the bank is from north-west to south-east, the size of the masses coming from the westward and thrown ashore must always be largest where the motion of the waves and currents is most violent. Colonel Reid states that all calcareous stones rolled along from the west are soon ground into sand, and in this form they pass round Portland Island.*

The storm of 1824 burst over the Chesil Bank with great fury, and the village of Chesilton, built upon its southern extremity, was overwhelmed, with many of the inhabitants. During another gale on the 23rd Nov., 1852, the south-west wind threw in upon the bank during the night and early part of the following day a mass of shingle amounting by

* See Palmer on Motion of Shingle Beaches, Phil. Trans. 1834, p. 568; and Col. Sir W. Reid, Papers of Royal Engineers, 1838, vol. ii. p. 128.

measurement, according to Mr. Coode, C.E., to no less than three and a half millions of tons.*

The storm before alluded to of 1824 carried away part of the Breakwater at Plymouth, and huge masses of rock, from two to five tons in weight, were lifted from the bottom of the weather side, and rolled fairly to the top of the pile. One block of limestone, weighing seven tons, was washed round the western extremity of the Breakwater, and carried 150 feet.† The propelling power is derived in these cases from the breaking of the waves, which run fastest in shallow water, and for a short space far exceed the most rapid currents in swiftness. It was in the same month, and also during a spring-tide, that a great flood is mentioned on the coasts of England, in the year 1099. Florence of Worcester says, 'On the third day of the nones of Nov. 1099, the sea came out upon the shore and buried towns and men very many, and oxen and sheep innumerable.' We also read in the Saxon Chronicle, for the year 1099, 'This year eke on St. Martin's mass day, the 11th of Novembre, sprung up so much of the sea flood, and so myckle harm did, as no man minded that it ever afore did, and there was the ylk day a new moon.'

South of the Bill, or southern point of Portland, is a remarkable shoal in the channel at the depth of seven fathoms, called 'the Shambles,' consisting entirely of rolled and broken shells of *Purpura lapillus*, *Mytilus edulis*, and other species now living. This mass of light materials is always in motion, varying in height from day to day, and yet the shoal remains constant.

Dorsetshire—Devonshire.—At Lyme Regis, in Dorsetshire, the 'Church Cliffs,' as they are called, consisting of lias about one hundred feet in height, gradually fell away at the rate of one yard a year, from 1800 to 1829.‡

An extraordinary landslip occurred on the 24th of December, 1839, on the coast in Devonshire between Lyme Regis and Axmouth, which has been described by the Rev. W. D. Conybeare, to whose kindness I am indebted

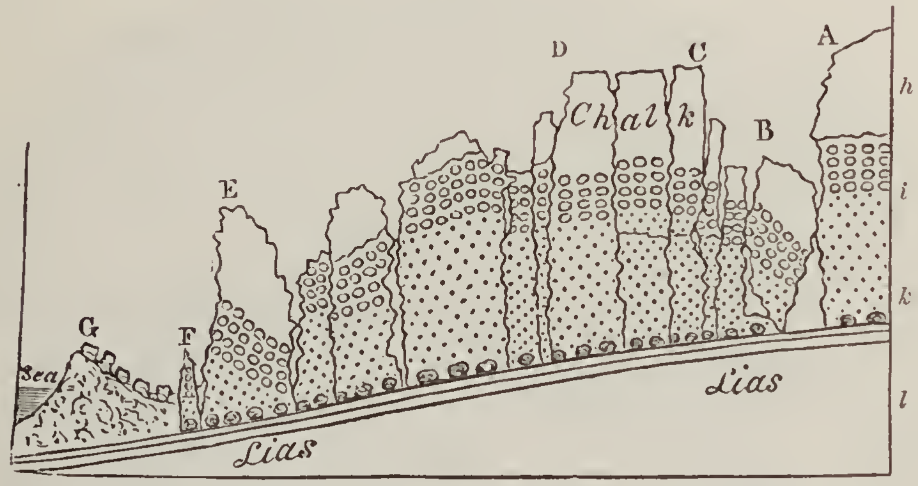
* Coode, Proc. Inst. of Civ. Engineers, 1852–3, vol. xii. p. 545.

† De la Beche, Geological Manual, p. 82.

‡ According to the measurement of Carpent of Lyme.

for the accompanying section, fig. 56. The tract of downs ranging there along the coast is capped by chalk (*h*), which rests on sandstone, alternating with chert (*i*), beneath which is more than 100 feet of loose sand (*k*), with concretions at the bottom, and belonging, like *i*, to the upper greensand formation or chloritic series; the whole of the above masses, *h*, *i*, *k*, repose on retentive beds of clay (*l*), belonging to the lias, which shelves towards the sea. Numerous springs issuing from the loose sand (*k*) have gradually removed portions of it, and thus undermined the superstratum, so as to have caused subsidences at former times,

Fig. 56.



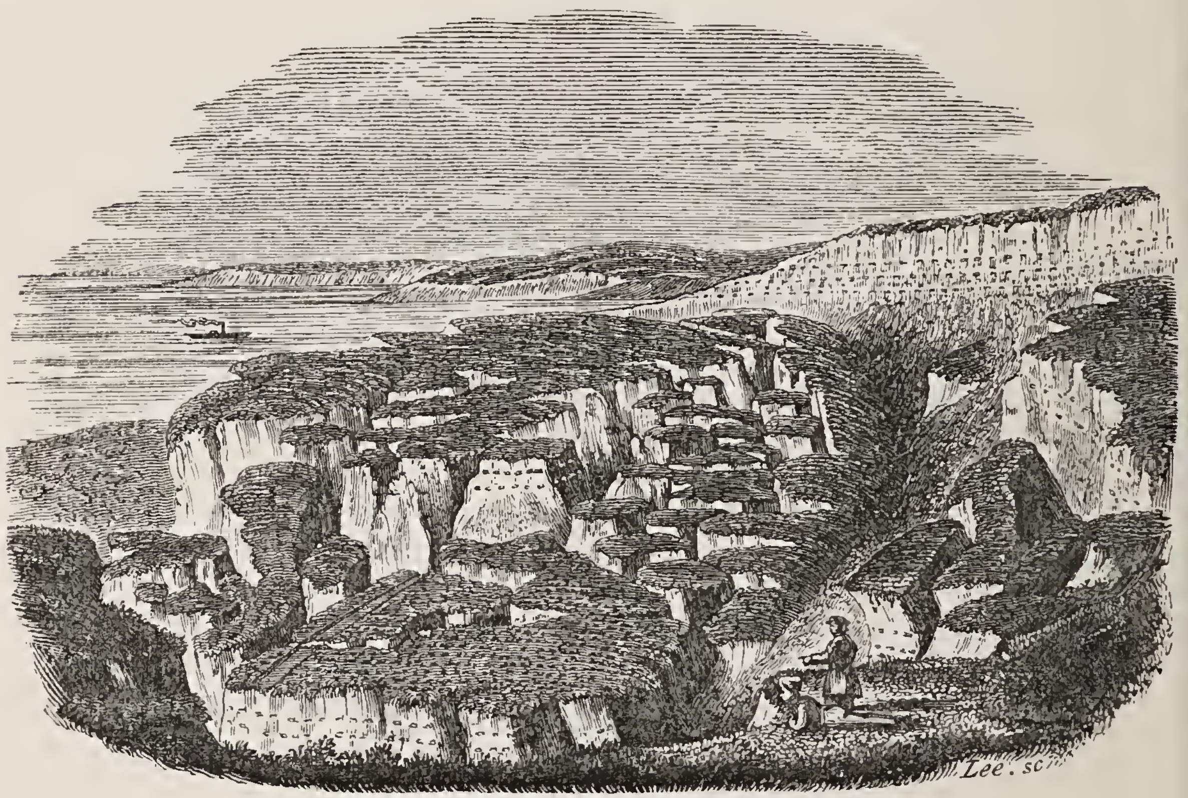
Landslip, near Axmouth, Dec. 1839. (Rev. W. D. Conybeare.)

A. Tract of Downs still remaining at their original level.
B. New ravine.
C, D. Sunk and fractured strip united to A, before the convulsion.
D, E. Bindon undercliff as before, but more fissured, and thrust forward about fifty feet toward the sea.
F. Pyramidal crag, sunk from seventy to twenty feet in height.
G. New reef upheaved from the sea.

and to have produced a line of undercliff between D and E. In 1839 an excessively wet season had saturated all the rocks with moisture, so as to increase the weight of the incumbent mass, from which the support had already been withdrawn by the action of springs. Thus the superstrata were precipitated into hollows prepared for them, and the adjacent masses of partially undermined rock, to which the movement was communicated, were made to slide down on a slippery basis of watery sand towards the sea. These causes

gave rise to a convulsion, which began on the morning of the 24th of December, with a crashing noise; and, on the evening of the same day, fissures were seen opening in the ground, and the walls of tenements rending and sinking, until a deep chasm or ravine, B, was formed extending nearly three-quarters of a mile in length, with a depth of from 100 to 150 feet, and a breadth exceeding 240 feet. At the bottom of this deep gulf lie fragments of the original surface thrown together in the wildest confusion. In consequence of lateral movements, the tract intervening between

Fig. 57.



View of the Axmouth landslip from Great Bindon, looking westward to the Sidmouth hills, and estuary of the Exe. From an original drawing by Mrs. Buckland.

the new fissure and the sea, including the ancient undercliff, was fractured, and the whole line of sea-cliff carried bodily forwards for many yards. 'A remarkable pyramidal crag, F, off Culverhole Point, which lately formed a distinguishing landmark, has sunk from a height of about seventy to twenty feet, and the main cliff, E, previously more than fifty feet distant from this insulated crag, is now brought almost close to it. This motion of the sea-cliff has produced a farther effect, which may rank among the most striking phenomena

of this catastrophe. The lateral pressure of the descending rocks has urged the neighbouring strata, extending beneath the shingle of the shore, by their state of unnatural condensation, to burst upwards in a line parallel to the coast—thus an elevated ridge, G, more than a mile in length, and rising more than forty feet, covered by a confused assemblage of broken strata, and immense blocks of rock, invested with sea-weed and corallines, and scattered over with shells and star-fish, and other productions of the deep, forms an extended reef in front of the present range of cliffs.*

A full account of this remarkable landslip, with a plan, sections, and many fine illustrative drawings, was published by Messrs. Conybeare and Buckland,† from one of which fig. 57 has been reduced.

Tor Bay.—The shores which bound Tor Bay give way continually at many points; their waste forms the subject of a memoir published by Mr. Pengelly, in 1861.‡ He has shown that thrice in the course of the last hundred years it has been necessary to carry the road between Torquay and Paignton farther inland. A solid mass of masonry, built for the protection of the present road, was swept away by the waves in a storm, in October 1859, at which time the neighbouring cliffs were also undermined at many points on the coast, comprising some precipitous rocks of limestone.

St. Michael's Mount, Cornwall.—When we reflect on the great amount of change caused by the undermining power of the waves, and by landslips in the last three or four centuries on our southern coasts, and the proofs of submergence of numerous forests which have sunk at some unknown period, and which extend here and there from the shore line to some distance out at sea; it becomes a matter of surprise that we should find a single point where the outline of the present coast can be demonstrated to have remained for nineteen centuries unaltered. For this reason St. Michael's Mount, in Cornwall, deserves our special attention, for it can be shown that all the characteristic features in its physical

* Rev. W. D. Conybeare, letter dated Axminster, Dec. 21, 1839.

† London, J. Murray, 1840.

‡ Geologist, vol. iv. p. 447. 1861.

geography have been retained throughout that long series of centuries identically such as they now are.

The Mount (see figs. 58, 59, and 60, pp. 545 and 546) consists chiefly of granite, with some slate rock, like that of the adjoining coast. It is 195 feet high, with precipitous sides, and is situated near the head of Mount's Bay, which is distant about ten miles eastward from the Land's End. Twice in every twenty-four hours is this mount an island, and twice when the tide falls it is connected by a narrow isthmus with the mainland. This isthmus is composed of the slate before mentioned, the same which enters into the structure of part of the Mount, where it is penetrated by veins of granite at the junction of the two formations. At the highest spring tides there is no less than twelve feet of water on the isthmus, and six at neap tides: in ordinary weather it is usually dry for five hours at low tide. The annexed views (p. 545) will give the reader an idea of the appearance of the Mount at high and low water.*

As there is no other rock on our coast which is twice alternately an island and a promontory every twenty-four hours, this circumstance alone would be almost conclusive in favour of the opinion, that the Mount is the Ictis of Diodorus Siculus. That historian, writing in the year 9 B.C., thus speaks of the trade of the ancients with Britain:—'The inhabitants of Belerium are hospitable, and, on account of their intercourse with strangers, civilised in their habits.' 'It is they who produce tin, which they melt into the form of astragali, and they carry it to an island in front of Britain, called Ictis. This island is left dry at low tides, and they then transport the tin in carts from the shore. Here the traders buy it from the natives, and carry it to Gaul, over which it travels on horseback in about thirty days, to the mouths of the Rhone.'

About the year 1823, a block of tin, now in the museum of the Royal Institute of Cornwall at Truro, was dredged up in Falmouth Harbour (see fig. 61). It has the form, says

* For the original of figs. 58 and 59, I am indebted to the kindness of Sir Henry James.

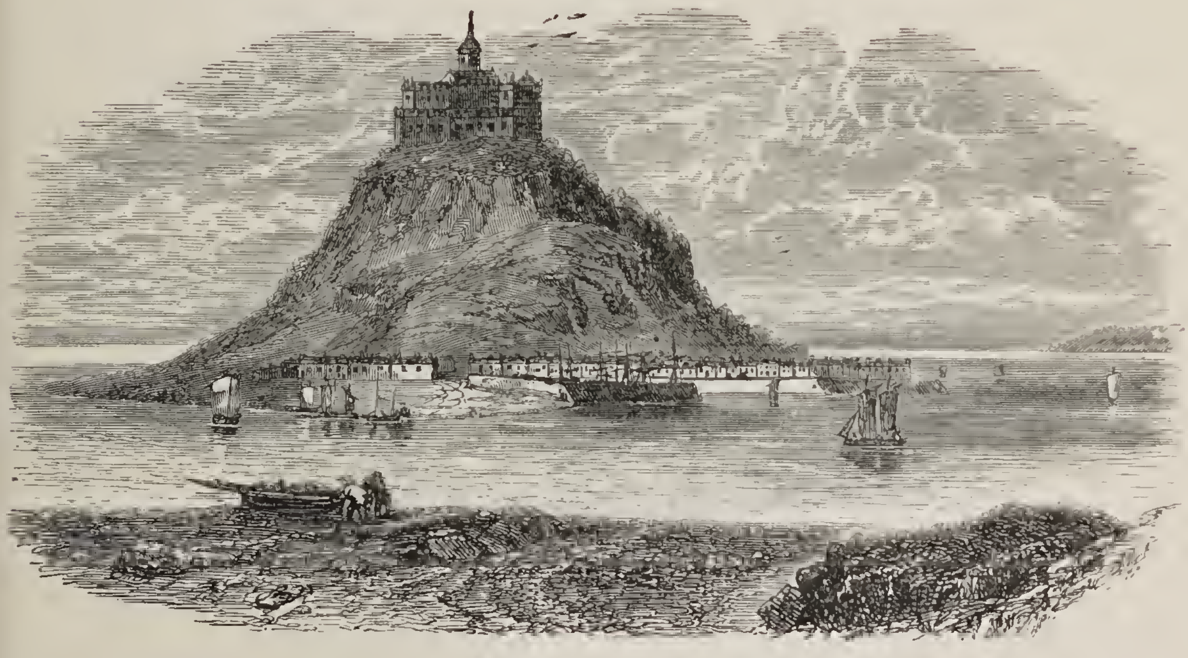
Sir H. James, which Diodorus might well have compared to an astragalus; one side slightly convex (see fig. 61), as if to

Fig. 58.

View of St. Michael's Mount at low tide.

enable it to fit the bottom of a boat, the whole being so shaped that it might be easily slung by cords on the side of a horse,

Fig. 59.



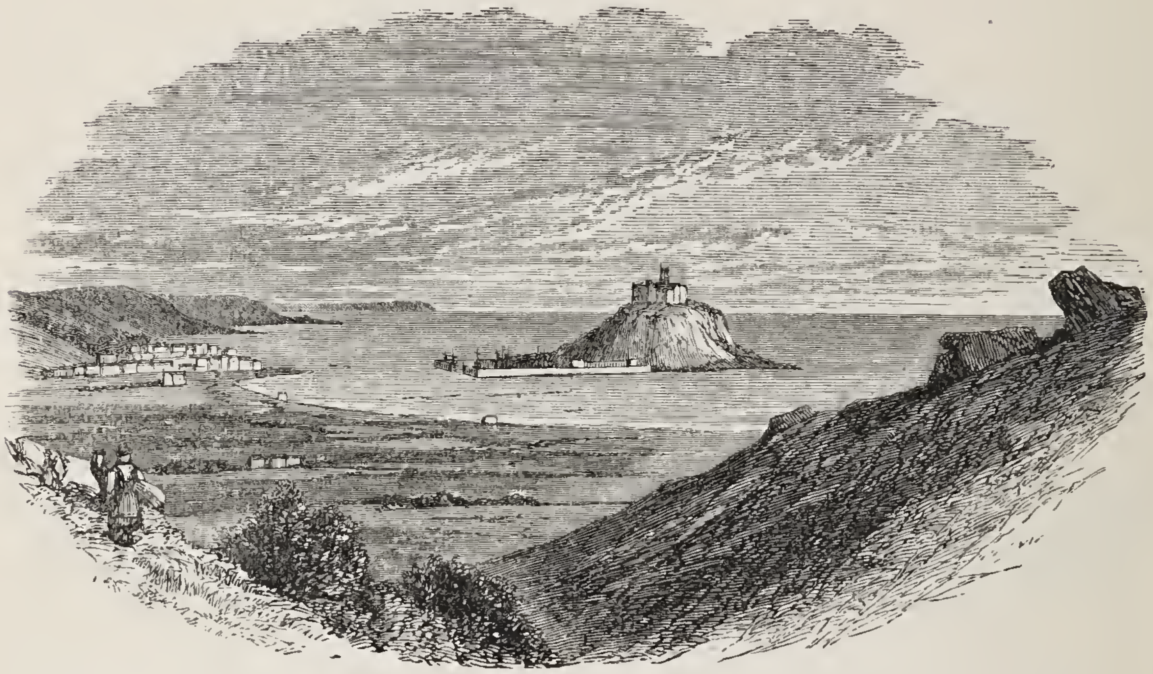
View of St. Michael's Mount at high tide.

and two of these balancing each other would constitute such a load as a horse might conveniently carry.* In addition to

* Col. Sir H. James on Block of Tin dredged up in Falmouth Harbour, 45th Annual Report Royal Inst. Cornwall, 1863.

the above considerations, Dr. Barham has shown that the Ictis of Diodorus not only answers geographically to St. Michael's

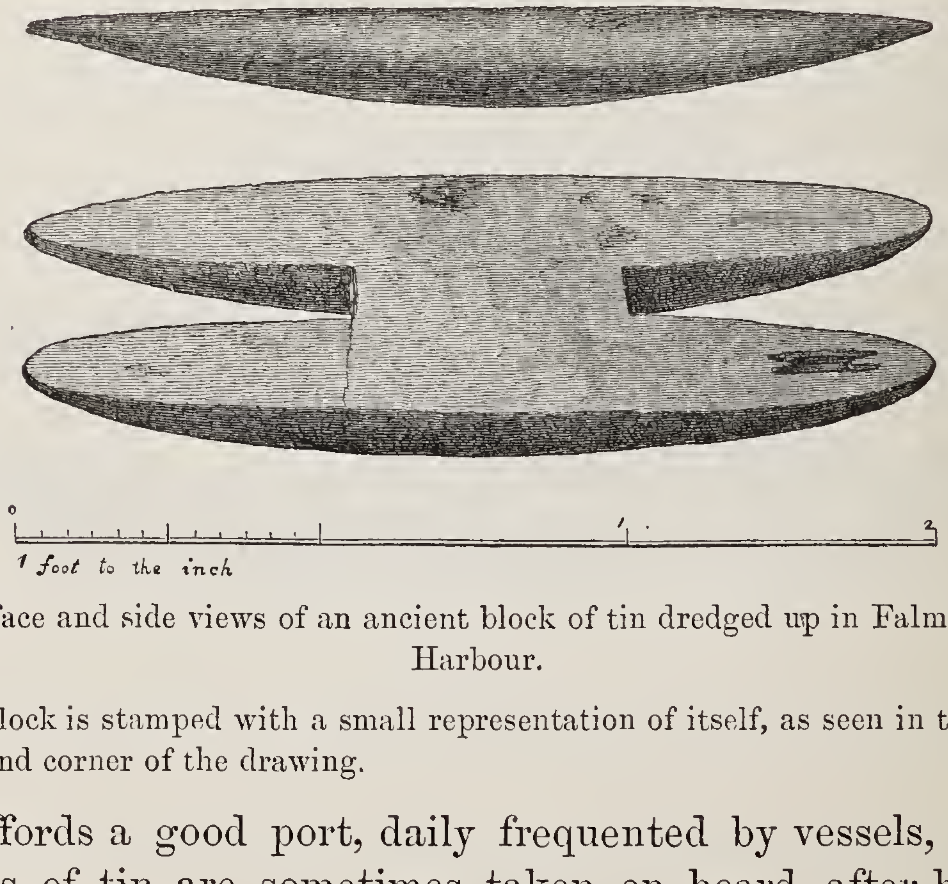
Fig. 60.



View of St. Michael's Mount at high tide, showing the position of the harbour and the town of Marazion, E.N.E. of the Mount.

Mount, but is just such a promontory as would have been selected by foreign traders as well adapted for defence. It

Fig. 61.



Surface and side views of an ancient block of tin dredged up in Falmouth Harbour.

The block is stamped with a small representation of itself, as seen in the lower right-hand corner of the drawing.

still affords a good port, daily frequented by vessels, where cargoes of tin are sometimes taken on board, after having

been transported, as in the olden time, at low tide across the isthmus. Colliers of 500 tons' burden can now enter the harbour, which is on the landward or sheltered side of the Mount (as seen in figs. 58, 60), and the depth of water would have sufficed to float the largest vessels which the Phœnicians and other ancient navigators employed when they traded with the Cassiterides, five, if not ten, centuries before the Christian era.

According to Carew, the old name of St. Michael's Mount, 'Caraclowse in Cowse,' signifies, in the Cornish language, 'The Hoare Rock in the wood,' and from this some have inferred that the rock was once surrounded with forest-covered land. At present there are no trees upon the Mount, only a few shrubs, and it is not easy to imagine how such a name could ever have been appropriate since the days of Diodorus, when the Mount was evidently already isolated, and the isthmus such as it is now. Mr. Pengelly has lately entered into a full discussion of this subject,* stating truly, that to make such a name appropriate, we are required to assume that the Mount was surrounded by land covered with trees; a geographical state of things which at once carries us back much more than nineteen centuries, and yet the Cornish language is assumed to have been spoken when the designation of the 'Rock in the Wood' was assigned to the Mount. Whether we endeavour to explain the altered geographical conditions by encroachments of the sea on the land, and the sweeping away of a low tract which once filled the bay, or by a general subsidence of the whole region to a lower level, we should have to assign a date to the old forest anterior to Phœnician times, and thus ascribe a fabulous antiquity to the Cornish tongue. Here, no doubt, as elsewhere, the waves have in the course of the last twenty or thirty centuries converted some tracts of land into sea. Near Penzance, for example, in the same bay, it is recorded that thirty-six acres of pasture land called 'the Green' have been gradually removed and reduced to a bare sandy beach, since the reign of Charles II. It is also known that the grandfather of the present Vicar of Madron (1865) received

* Pengelly, Papers read at Brit. Assoc., Birmingham, 1865.

tithe for land which was situated under the cliff at Penzance. Mr. Pengelly also mentions that the coast near Marazion (see fig. 60), which is only a third of a mile distant from the Mount, has yielded slowly at some points within the memory of persons now living, but so gradually that the rate of waste cannot have exceeded ten feet per century; and he calculates that if this cause of change is alone appealed to, it would have taken ten thousand years or more, before our time, to remove so much land as would have stretched from the mainland to the Mount. On the other hand, it is a somewhat forced hypothesis to assume that whereas a retrospect of nineteen centuries displays to us the Mount geographically the same as it now is, yet shortly before that time, when Cornish was spoken, there was a sinking down and submergence of a wooded tract.

There have certainly been depressions here, as in so many other parts of the English coast, but they may have happened very long before the time of history. Thus for example, between Newlyn and St. Michael's Mount, as Boase relates,* there is seen under the sand black vegetable mould full of hazel-nuts, and the branches, leaves, and trunks of forest trees, the elm among others, all of indigenous species. The roots are seen in the soil in their natural position. The wing-cases of insects have also been found among the vegetable matter. The stratum has been traced seaward as far as the ebb permits, and it implies the downward movement of a level tract which preserved its horizontality when subsiding. If we endeavour to form a conjecture as to the probable date of such a submergence, we find ourselves involved in a geological enquiry of vast extent, although the event is so modern as to be comprised within the human period. Thus, to revert again to the Devonshire coast, there is a submerged forest at Torquay, and much peaty matter resting on bluish clay, which may be traced from the neighbourhood of Tor Abbey, at a height of about eighty-four feet above the sea, for three-quarters of a mile to the shore. The same bed extends to an unknown distance seaward, many stumps and roots of trees being observed

* Boase, cited by De la Beche in his Report on the Geology of Devon, &c., chap. xiii.

firmly fixed in the clay, and bones of the deer, wild hog, horse, and the extinct *Bos longifrons* occurring in the peat; with these, the antler of a red-deer was observed by Mr. Pengelly, having several cuts on it made by a sharp instrument, and the whole fashioned into a tool for piercing. From this forest-bed, at a point in the bay where there is a depth of more than thirty feet of water, the fishermen drew up in their trawl, a few years before 1851, the molar tooth of the mammoth, or *Elephas primigenius*, stained with the black colour of the peat, and retaining much of its animal matter, its fresh condition being probably due to the antiseptic quality of the peat. The specimen is now in the Torquay Museum, and it is interesting as serving to establish the fact that the mammoth survived when the surface of this region had already acquired its present configuration, so far as relates to the direction and depth of the valleys in the bottom of one of which the peat alluded to was formed. I mention these facts to show that submarine forests on this coast cannot be safely appealed to in confirmation of changes which may have occurred in the historical period. They may belong to the close of the paleolithic era, although long subsequent to the filling of the caves of Brixham and Kent's Hole, near Torquay, when the elephant, rhinoceros, and cave-bear co-existed with man, before the excavation of some of the valleys which now descend to the sea on this coast.

To return to Cornwall: the oldest historians mention a tradition of the submersion of the Lionnesse, a country said to have stretched from the Land's End to the Scilly Islands. The tract, if it ever existed, must have been thirty miles in length, and perhaps ten in breadth. The land now remaining on either side is from two hundred to three hundred feet high; the intervening sea about three hundred feet deep. Although there is no authentic evidence for this romantic tale, it probably originated in some former inroads of the Atlantic, accompanying, perhaps, a subsidence of land on this coast.

If we then turn to the Bristol Channel, we find that both on the north and south sides of it there are numerous remains of submerged forests; to one of these, at Porlock Bay,

on the coast of Somersetshire, Mr. Godwin-Austen * has lately called particular attention, and has shown that it extends far from the land. There is indeed good reason to believe that there was once a woodland tract uniting Somersetshire and Wales, through the middle of which the ancient Severn flowed. The former existence of such land enables us to comprehend how along the southern coast of Glamorganshire fissures and caves in the face of precipitous cliffs, at the base of which the sea now beats, may have been inhabited by the hyena and bear, or became the receptacles of the bones of the elephant, rhinoceros, tiger, reindeer and other quadrupeds, most of them now extinct. In one of these caves no less than 1,000 antlers of the reindeer were found.

At St. Bride's Bay, in Pembrokeshire, and proceeding farther to the north in Cardiganshire and again in North Wales (as in Anglesea and Denbighshire), we have repetitions of the same appearances of ancient forests adjoining the coast. One of these in Anglesea reminds us in a striking manner of the phenomena before mentioned as characterising the forest-bed of Tor Abbey. A bed of peat three feet thick, with the stumps and roots of trees, was observed by the Honourable W. Stanley, exposed at low water in the harbour of Holyhead, and stretching upwards to a slight elevation above the sea, where the excavations made for the railway in 1849 brought to light two perfect heads of the mammoth. The tusks and molars lay two feet below the surface in the peat, which was covered by the stiff blue clay.† It is not improbable that this mammoth survived most of the lost species which were its contemporaries in what has been called the Cavern period. At the same time, we must not forget that the fauna, not only of the bronze age, but of the oldest lake-dwellers of Switzerland to whom the use of metals was unknown, was identical with that of the historical era, no mixture of the bones of the mammoth or of *Bos longifrons*, or even of the reindeer, having been detected, whether among the wild or domestic animals of the lacustrine habitations

* Quart. Geol. Journ. 1866, vol. xxii. p. 1.

† One of these skulls, referred by Prof. Owen to *Elephas primigenius*, has been presented to the British Museum by the Hon. W. Stanley, M.P., on whose property they were found.

of Switzerland or in the kitchen-middens of Denmark. If, therefore, all the littoral, sunk forests of the south and west of England are referable to about the same geological period, the occasional presence in them of the mammoth will entitle them to be regarded as very ancient, or of a date intervening between the era of the lake-dwellings and that of the oldest epoch to which man has yet been traced back.

West coast of England.—Having now brought together an ample body of proofs of the destructive operations of the waves, tides, and currents, on our eastern and southern shores, it will be unnecessary to enter into details of changes on the western coast, for they present merely a repetition of the same phenomena, and in general on an inferior scale. On the borders of the estuary of the Severn the flats of Somersetshire and Gloucestershire have received enormous accessions, while, on the other hand, the coast of Cheshire, between the rivers Mersey and Dee, has lost, since the year 1764, many hundred yards, and some affirm more than half a mile, by the advance of the sea upon the abrupt cliffs of red clay and marls. Within the period above mentioned several lighthouses have been successively abandoned.* There are traditions in Pembrokeshire † and Cardiganshire ‡ of far greater losses of territory than that which the Lionnesse tale of Cornwall pretends to commemorate. They are all important, as demonstrating that the earliest inhabitants were familiar with the phenomenon of incursions of the sea.

Loss of land on the coast of France.—The French coast, particularly that of Brittany, where the tides rise to an extraordinary height, is the constant prey of the waves. In the ninth century many villages and woods are reported to have been carried away, the coast undergoing great change, whereby the hill of St. Michel was detached from the mainland. The parish of Bourgneuf, and several others in that neighbourhood, were overflowed in the year 1500. In 1735, during a great storm, the ruins of Palnel were seen uncovered in the sea.§

* Stevenson, Jameson's Ed. New Phil. Journ. No 8. p. 386.

† Camden, who cites Giraldus; also Ray, 'On the Deluge,' Phys. Theol., p. 228.

‡ Meyrick's Cardigan.

§ Von Hoff, Geschichte, &c. vol. i. p. 49.

CHAPTER XXI.

ACTION OF TIDES AND CURRENTS—*continued.*

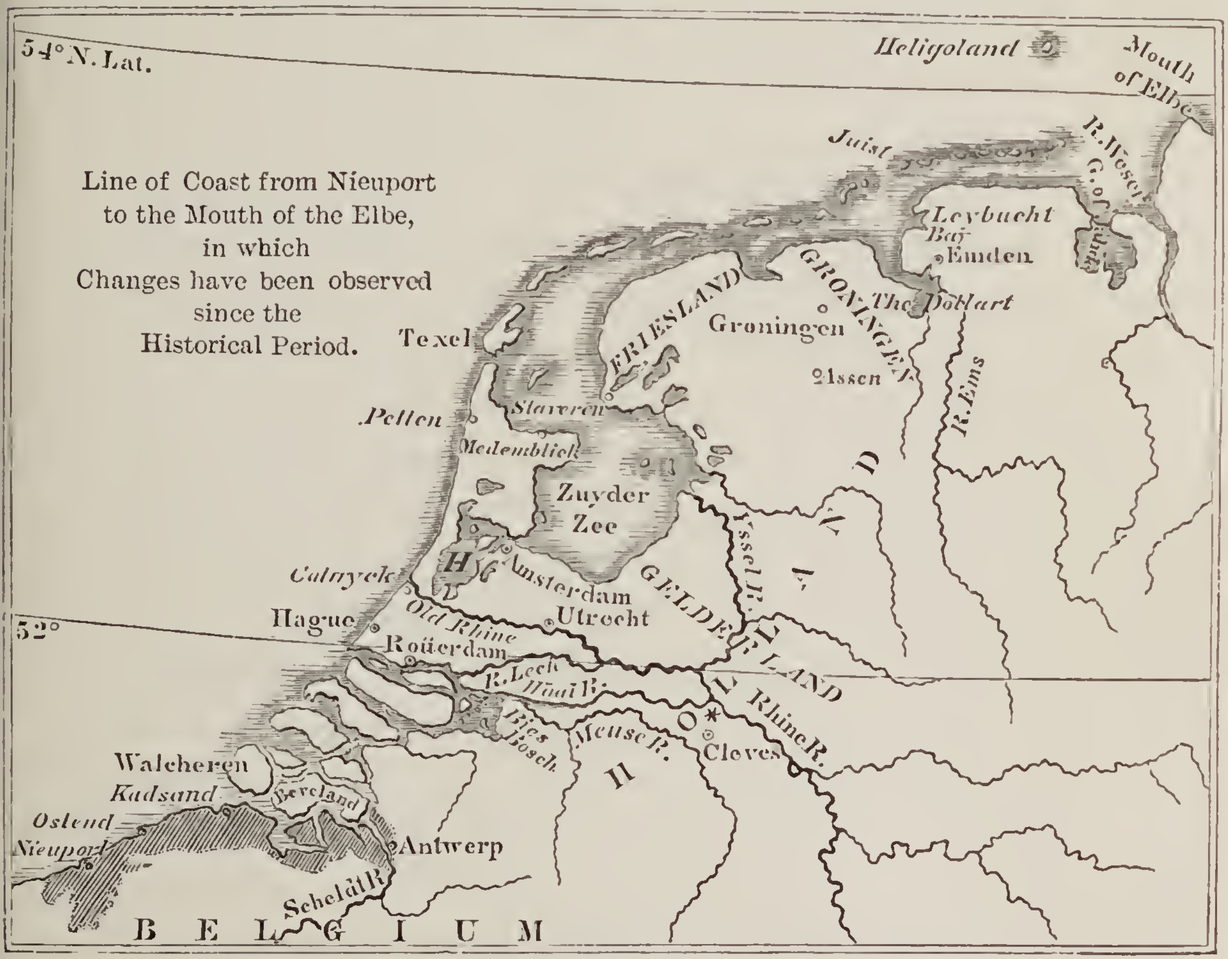
INROADS OF THE SEA AT THE MOUTHS OF THE RHINE IN HOLLAND—CHANGES IN THE ARMS OF THE RHINE—PROOFS OF SUBSIDENCE OF LAND—ESTUARY OF THE BIES BOSCH, FORMED IN 1421—ZUYDER ZEE, IN THE THIRTEENTH CENTURY—ISLANDS DESTROYED—DELTA OF THE EMS CONVERTED INTO A BAY—ESTUARY OF THE DOLLART FORMED—ENCROACHMENT OF THE SEA ON THE COAST OF SLESWICK—ON THE SHORES OF NORTH AMERICA—BALTIC CURRENTS—CIMBRIAN DELUGE—TIDAL WAVE, CALLED THE BORE.

Inroads of the sea at the mouths of the Rhine.—THE line of British coast considered in the preceding chapter offered no example of the conflict of two great antagonistic forces; the influx, on the one hand, of a river draining a large continent, and, on the other, the action of the waves, tides, and currents of the ocean. But when we pass over by the Straits of Dover to the Continent, and proceed north-eastwards, we find an admirable illustration of such a contest, where the ocean and the Rhine are opposed to each other, each disputing the ground now occupied by Holland; the one striving to shape out an estuary, the other to form a delta. There was evidently a period when the river obtained the ascendency, when the shape and perhaps the relative level of the coast and set of the tides were very different; but for the last two thousand years, during which man has witnessed and actively participated in the struggle, the result has been in favour of the ocean; the area of the whole territory having become more and more circumscribed; natural and artificial barriers have given way, one after another; and many hundred thousand human beings have perished in the waves.

Changes in the arms of the Rhine.—The Rhine, after flowing from the Grison Alps, copiously charged with sediment, first purifies itself in the Lake of Constance, where a large delta

is formed; then swelled by the Aar and numerous other tributaries, it flows for more than six hundred miles towards the north; when, entering a low tract, it divides into two arms, about ten miles north-east of Cleves,—a point which may be considered the head of its delta. (See*, map, fig. 62.) In speaking of the delta, I do not mean to assume that all that part of Holland which is comprised within the several arms of the Rhine can be called a delta in the

Fig. 62.



The dark tint between Antwerp and Nieuport represents part of the Netherlands which was land in the time of the Romans, then overflowed by the sea before and during the 5th century, and afterwards reconverted into land.

The letter H west of Amsterdam indicates the Lake of Haarlem drained in 1853, and turned into arable land 13 feet below the sea-level.

strictest sense of the term; because some portion of the country thus circumscribed, as, for example, a part of Gelderland and Utrecht, consists of strata which may have been deposited in the sea before the Rhine existed. These older tracts may either have been raised like the Ullah Bund in

Cutch, during the period when the sediment of the Rhine was converting a part of the sea into land, or they may have constituted islands previously.

When the river divides north of Cleves, the left arm takes the name of the Waal; and the right, retaining that of the Rhine, is connected, a little farther to the north, by an artificial canal with the river Yssel. The Rhine then flowing westward divides again south-east of Utrecht, and from this point it takes the name of the Leck, a name which was given to distinguish it from the northern arm called the Old Rhine, which was sanded up until after the year 1825, when a channel was cut for it, by which it now enters the sea at Catwyck. It is common, in all great deltas, that the principal channels of discharge should shift from time to time, but in Holland so many magnificent canals have been constructed, and have so diverted, from time to time, the course of the waters, that the geographical changes in this delta are endless, and their history, since the Roman era, forms a complicated topic of antiquarian research. The present head of the delta is about forty geographical miles from the nearest part of the gulf called the Zuyder Zee, and more than twice that distance from the general coast-line. The present head of the delta of the Nile is about 80 or 90 geographical miles from the sea; that of the Ganges, as before stated, 220; and that of the Mississippi about 180, reckoning from the point where the Atchafalaya branches off to the extremity of the new tongue of land in the Gulf of Mexico. But the comparative distance between the heads of deltas and the sea affords no positive data for estimating the relative magnitude of the alluvial tracts formed by their respective rivers, for the ramifications depend on many varying and temporary circumstances, and the area over which they extend does not hold any constant proportion to the volume of water in the river.

The Rhine, for instance, has at present three mouths. About two-thirds of its waters flow to the sea by the Waal, and the remainder is carried partly to the Zuyder Zee by the Yssel, and partly to the ocean by the Leck. As the whole coast to the south as far as Ostend, and on the north to the entrance of the Baltic, has, with few exceptions, from time

immemorial, yielded to the force of the waves, it is evident that the common delta of the Rhine, Meuse, and Scheldt (for these three rivers may all be considered as discharging their waters into the same part of the sea), would, if its advance had not been checked, have become extremely prominent; and even if it had remained stationary, would long ere this have projected far beyond the rounded outline of the coast, like that strip of land already described at the mouth of the Mississippi. But we find, on the contrary, that the islands which skirt the coast have not only lessened in size, but in number also, while great bays have been formed in the interior by incursions of the sea.

In order to explain the incessant advance of the ocean on the shores and inland country of Holland, M. E. de Beaumont has suggested that there has in all probability been a general depression or sinking of the land below its former level over a wide area. Such a change of level would enable the sea to break through the ancient line of sand-banks and islands which protected the coast—would lead to the enlargement of bays, the formation of new estuaries, and ultimately to the entire submergence of land. These views appear to be supported by the fact that several peat-mosses of fresh-water origin now occur under the level of the sea, especially on the site of the Zuyder Zee and Lake Flevo, presently to be mentioned. Several excavations also made for wells at Utrecht, Amsterdam, and Rotterdam have proved, that below the level of the ocean, the soil near the coast consists of alternations of sand with marine shells, and beds of peat and clay, which have been traced to the depth of fifty feet and upwards.*

I have said that the coast to the south as far as Ostend has given way. This statement may at first seem opposed to the fact, that the tract between Antwerp and Nieuport, shaded black in the map (fig. 62, p. 553), although now dry land, and supporting a large population, has, within the historical period, been covered with the sea. This region, however, consisted, in the time of the Romans, of woods, marshes, and peat-mosses, protected from the ocean by a

* M. E. de Beaumont, Géologie Pratique, vol. i. p. 316, and ibid. p. 260.

chain of sandy dunes, which were afterwards broken through during storms, especially in the fifth century. The waters of the sea during these irruptions threw down upon the barren peat a horizontal bed of fertile clay, which is in some places three yards thick, full of recent shells and works of art. The inhabitants, by the aid of embankments and the sand dunes of the coast, have succeeded, although not without frequent disasters, in defending the soil thus raised by the marine deposit.*

Inroads of the sea in Holland.—If we pass to the northward of the territory just alluded to, and cross the Scheldt, we find that between the fourteenth and eighteenth centuries parts of the islands Walcheren and Beveland were swept away, and several populous districts of Kadsand—losses which far more than counterbalance the gain of land caused by the sanding-up of some pre-existing creeks. In 1658 the island Orisant was annihilated. One of the most memorable inroads of the sea occurred in 1421, when the tide, pouring into the mouth of the united Meuse and Waal, burst through a dam in the district between Dort and Gertrudenberg, and overflowed seventy-two villages, forming a large sheet of water called the Bies Bosch. (See map, fig. 62.) Thirty-five of the villages were irretrievably lost, and no vestige, even of their ruins, was afterwards seen. The rest were redeemed, and the site of the others, though still very generally represented on maps as an estuary, has in fact been gradually filled up by alluvial deposits, and had become in 1835, as I was informed by Professor Moll, an immense plain, yielding abundant crops of hay, though still uninhabited. To the north of the Meuse is a long line of shore covered with sand dunes, where great encroachments have taken place from time to time, in consequence chiefly of the prevalence of south-easterly winds, which blow down the sands towards the sea. The church of Scheveningen, not far from the Hague, was once in the middle of the village, and now stands on the shore, half the place having been overwhelmed by the waves in 1570. Catwyck, once far from the

* Belpaire, Mém. de l'Acad. Roy. de Bruxelles, tom. x. 1837. Dumont, Bulletin of the same Soc. tom. v. p. 643.

sea, is now upon the shore; two of its streets having been overflowed, and land torn away to the extent of 200 yards in 1719. It is only by aid of embankments that Petten, and several other places farther north, have been defended against the sea.

In 1853 the Dutch Government laid dry, by means of steam power, a great sheet of water westward of Amsterdam, formerly called the Lake of Haarlem, and so represented in our map, H (fig. 62), extending over 45,000 acres. This gained land lies thirteen feet beneath the mean level of the ocean; and in 1859, when I visited it, supported an agricultural population of 5,000 souls.*

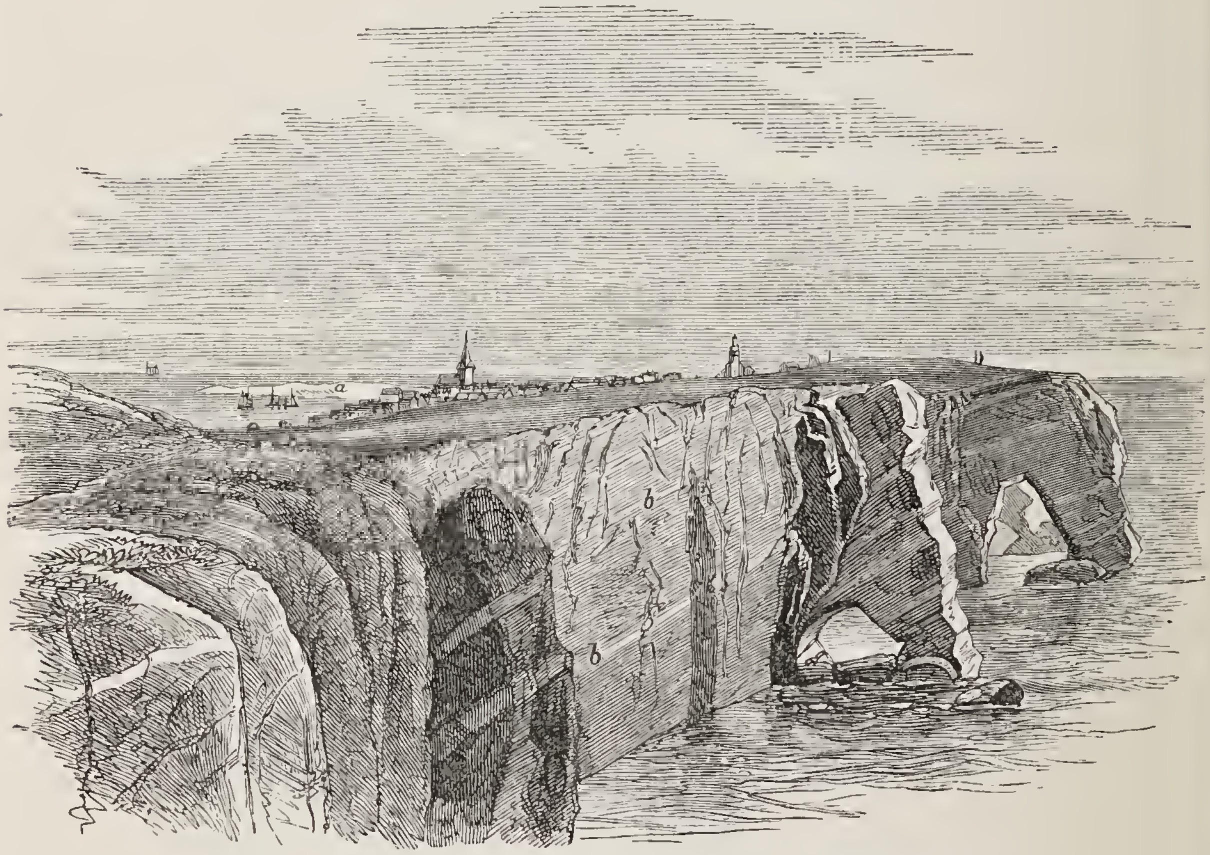
Formation of the Zuyder Zee and Straits of Staveren.—Still more important are the changes which have taken place on the coast opposite the right arm of the Rhine, or the Yssel, where the ocean has burst through a large isthmus, and entered the inland lake Flevo, which, in ancient times, was, according to Pomponius Mela, formed by the overflowing of the Rhine over certain lowlands. It appears that, in the time of Tacitus, there were several lakes on the present site of the Zuyder Zee, between Friesland and Holland. The successive inroads by which these, and a great part of the adjoining territory, were transformed into a great gulf, began about the commencement, and were completed towards the close, of the thirteenth century. Alting gives the following relation of the occurrence, drawn from manuscript documents of contemporary inhabitants of the neighbouring provinces. In the year 1205, the island now called Wieringen, to the south of the Texel, was still a part of the mainland, but during several high floods, of which the dates are given, ending in December 1251, it was separated from the continent. By subsequent incursions, the sea consumed great parts of the rich and populous isthmus, a low tract which stretched on the north of Lake Flevo, between Staveren in Friesland and Medemblick in Holland (see map, fig. 62), till at length a breach was completed about the year 1282, and afterwards widened. Great destruction of land took

* For a fuller description of this drained tract, see Lyell's 'Antiquity of Man.' p. 147.

place when the sea first broke in, and many towns were swept away; but there was afterwards a reaction to a certain extent, large tracts, at first submerged, having been gradually redeemed. The new straits south of Staveren are more than half the width of those of Dover, but are very shallow, the greatest depth not exceeding two or three fathoms. The new bay is of a somewhat circular form, and between *thirty* and *forty* miles in diameter. How much of this space may formerly have been occupied by Lake Flevo is unknown.

Destruction of islands.—A series of islands stretching from

Fig. 63.



View of part of the island of Heligoland, with Sandy Island.

a. Sandy Island in the distance, said to have been formerly united with the main island.
b b. Strata of a light green colour separating the beds of red marl and sandstone.

the Texel to the mouths of the Weser and Elbe are probably the last relics of a tract once continuous. They have greatly diminished in size, and have lost about a third of their number, since the time of Pliny; for that naturalist counted twenty-three islands between the Texel and the Eider, in Schleswig-Holstein, whereas there are now only sixteen, in-

cluding Heligoland and Neuwerk.* The island of Heligoland, at the mouth of the Elbe, consists of a rock of red marl and sandstone of the Trias formation (or Keuper and Bunter of the Germans), and is bounded by perpendicular red cliffs, above 200 feet high. (See fig. 63.) Although, according to some accounts, it has been greatly reduced in size since the year 800, M. Wiebel assures us that the ancient map by Meyer cannot be depended upon, and that the island, according to the description still extant by Adam of Bremen, was not much larger than now in the time of Charlemagne. On comparing the map made in the year 1793 by the Danish engineer Wessel, the average encroachment of the sea on the cliffs, between that period and 1848 (or about half a century), amounted to about three feet a year for the whole circumference of the island.† According to some authorities, Sandy Island (see *a*, fig. 63), now separated from Heligoland by a navigable channel, formed, within the memory of man, a portion of the larger island. On the other hand, some few islands off the Dutch and Danish coasts have extended their bounds in one direction, or become connected with others, by the sanding-up of channels; but even these, like Juist, have generally given way as much on the north towards the sea as they have gained on the south, or land side.

The Dollart formed.—While the delta of the Rhine has suffered so materially from the movements of the ocean, it can hardly be supposed that minor rivers on the same coast should have been permitted to extend their deltas. It appears that in the time of the Romans there was an alluvial plain of great fertility, where the Ems entered the sea by three arms. This low country stretched between Groningen and Friesland, and sent out a peninsula to the north-east towards Emden. (See map, fig. 62.) A flood in 1277 first destroyed part of the peninsula. Other inundations followed at different periods throughout the fifteenth century. In 1507, a part only of Torum, a considerable town, remained standing; and in spite of the erection of dams, the remainder

* Von Hoff, vol. i. p. 364.

† Quart. Journ. Geol. Soc. vol. iv. p. 32; Memoirs.

of that place, together with market-towns, villages, and monasteries, to the number of fifty, were finally overwhelmed. The new gulf, which was called the Dollart, although small in comparison to the Zuyder Zee, occupied no less than six square miles at first; but part of this space was, in the course of the two following centuries, again redeemed from the sea. The small bay of Leybucht, farther north, was formed in a similar manner in the thirteenth century; and the bay of Harlbucht in the middle of the sixteenth. Both of these have since been partially reconverted into dry land. Another new estuary, called the Gulf of Jahde, near the mouth of the Weser, scarcely inferior in size to the Dollart, has been gradually hollowed out since the year 1016, between which era and 1651 a space of about four square miles has been added to the sea. The rivulet which now enters this inlet is very small; but Aren conjectures that an arm of the Weser had once an outlet in that direction.

Coast of Schleswig.—Farther north we find so many records of waste on the western coast of Schleswig, as to lead us to anticipate that, at no distant period in the history of the physical geography of Europe, Jutland may become an island, and the ocean may obtain a more direct entrance into the Baltic. Indeed, the temporary insulation of the northern extremity of Jutland has been effected no less than four times within the records of history, the ocean having as often made a breach through the bar of sand, which usually excludes it from the Lym Fiord. This long frith is 120 miles in length, including its windings, and communicates at its eastern end with the Baltic. The last irruption of salt water happened in 1824, and the fiord was still open in 1837, when some vessels of thirty tons' burden passed through.

The Marsh islands between the rivers Elbe and Eider are mere banks, like the lands formed of the 'warp' in the Humber, protected by dikes. Some of them, after having been inhabited with security for more than ten centuries, have been suddenly overwhelmed. In this manner, in 1216, no less than 10,000 of the inhabitants of Eiderstede and Ditmarsch perished; and on the 11th of October, 1634, the

islands and the whole coast, as far as Jutland, suffered by a dreadful deluge.

Destruction of Nordstrand by the sea.—Nordstrand, up to the year 1240, was, with the islands Sylt and Föhr (see map, fig. 64), so nearly connected with the mainland as to appear

Fig. 64.

Line of coast from the north of Holland to the Baltic, showing the position of islands which have suffered waste in the historical period.

a peninsula, and was called North Friesland, a highly cultivated and populous district. It measured from nine to eleven geographical miles from north to south, and six to eight from east to west. In the above-mentioned year it was torn asunder from the continent, and in part overwhelmed. The

Isle of Nordstrand, thus formed, was, towards the end of the sixteenth century, only sixteen geographical miles in circumference, and was still celebrated for its cultivation and numerous population. After many losses, it still contained 9,000 inhabitants. At last, in the year 1634, on the evening of the 11th of October, a flood passed over the whole island, whereby 1,300 houses, with many churches, were lost; above 6,000 men perished, and 50,000 head of cattle. Three small islets, one of them still called Nordstrand, alone remained, which are now continually wasting.

The redundancy of river water in the Baltic, especially during the melting of ice and snow in spring, causes in general an outward current through the channel called the Cattegat. But after an unusual continuance of north-westerly gales, especially during the height of the spring-tides, the Atlantic rises, and pouring a flood of water into the Baltic, commits dreadful devastations on the isles of the Danish Archipelago. This current even acts, though with diminished force, as far eastward as the vicinity of Dantzic.* Accounts written during the last ten centuries attest the wearing down of promontories on the Danish coast, the deepening of gulfs, the severing of peninsulas from the mainland, and the waste of islands, while in several cases marsh land, defended for centuries by dikes, has at last been overflowed, and thousands of the inhabitants overwhelmed in the waves. Thus the island Barsoe, on the coast of Schleswig (see fig. 64), has lost, year after year, an acre at a time, and the island Alsen suffers in like manner.

Cimbrian deluge.—As we have already seen that, during the flood above mentioned, 6,000 men and 50,000 head of cattle perished on Nordstrand, on the western coast of Jutland, we are well prepared to find that this peninsula, the Cimbrica Chersonesus of the ancients, has from a remote period been the theatre of like catastrophes. Accordingly, Strabo records a story, although he treats it as an incredible fiction, that, during a high tide, the ocean rose upon this coast so rapidly that men on horseback were scarcely able to escape.†

* See examples in Von Hoff, vol. i. p. 73, who cites Pisansky.

† Book vii. Cimbri.

Florus, alluding to the same tradition, says, 'The Cimbrians, Teutons, and Tigurini, flying from the extreme limits of Gaul, when the ocean had overflowed their territory, were looking out in all parts of the world for new settlements.'* This event, commonly called the 'Cimbrian Deluge,' is supposed to have happened about three centuries before the Christian era; but it is not improbable that the principal catastrophe was preceded and followed by many devastations like those experienced in modern times on the islands and shores of Jutland, and such calamities may well be conceived to have forced on the migration of some maritime tribes.

Inroads of the sea on the eastern shores of North America.—After so many authentic details respecting the destruction of the coast in parts of Europe best known, it will be unnecessary to multiply examples of analogous changes in more distant regions of the world. It must not, however, be imagined that our own sea coasts are wearing away at an exceptionally rapid rate. Thus, for example, if we pass over to the eastern coast of North America, where the tides rise in the Bay of Fundy to a great elevation, we find many facts attesting the incessant demolition of land. Cliffs, of ten several hundred feet high, composed of sandstone, red marl, and other rocks, which border that bay and its numerous estuaries, are perpetually undermined. The ruins of these cliffs are gradually carried, in the form of mud, sand, and large boulders, into the Atlantic by powerful currents, aided at certain seasons by drift ice, which forms along the coast, and freezes round large stones.

At Cape May, on the north side of Delaware Bay, in the United States, the encroachment of the sea was shown by observations made consecutively for sixteen years, from 1804 to 1820, to average about nine feet a year;† and at Sullivan's Island, which lies on the north side of the entrance of the harbour of Charlestown, in South Carolina, the sea carried away a quarter of a mile of land in three years ending in 1786.‡

* 'Cimbri, Teutoni, atque Tigurini, ab extremis Galliæ profugi, cum terras eorum inundasset Oceanus, novas sedes toto orbe quærebant.'—Lib. iii. cap. 3.

† New Monthly Mag. vol. vi. p. 69.

‡ Von Hoff, vol. i. p. 96.

Tidal wave called 'the Bore.'—Before concluding my remarks on the action of the tides, I must not omit to mention the wave called 'the Bore,' which is sometimes produced in a river where a large body of water is made to rise suddenly, in consequence of the narrowing of the channel. The wave terminates abruptly on the inland side; because the quantity of water contained in it is so great, and its motion so rapid, that time is not allowed for the surface of the river to be immediately raised by means of transmitted pressure. A tide wave thus rendered abrupt has a close analogy, observes Dr. Whewell, to the waves which curl over and break on a shelving shore.*

The Bore which enters the Severn, where the phenomenon is of almost daily occurrence, is sometimes nine feet high, and at spring-tides rushes up the estuary with extraordinary rapidity. The finest example which I have seen of this wave was in Nova Scotia,† where the tide is said to rise in some places seventy feet perpendicular, and to be the highest in the world. In the large estuary of the Shubenacadie, which is connected with another estuary called the Basin of Mines, itself an embranchment of the Bay of Fundy, a vast body of water comes rushing up, with a roaring noise, into a long narrow channel, and while it is ascending, has all the appearance of pouring down a slope as steep as that of the celebrated rapids of the St. Lawrence. In picturesque effect, however, it bears no comparison, for instead of the transparent green water and snow-white foam of the St. Lawrence, the whole current of the Shubenacadie is turbid and densely charged with red mud. The same phenomenon is frequently witnessed in the principal branches of the Ganges and in the Megna as before mentioned (p. 475). 'In the Hoogly,' says Rennell, 'the Bore commences at Hoogly Point, the place where the river first contracts itself, and is perceptible above Hoogly Town; and so quick is its motion, that it hardly employs four hours in travelling from one to the other, though the distance is nearly seventy miles. At Calcutta it sometimes occasions an instantaneous rise of five

* Phil. Trans. 1833, p. 204.

† See Lyell's Travels in North America, in 1842, vol. ii. p. 166. London, 1845.

feet; and both here, and in every other part of its track, the boats, on its approach, immediately quit the shore, and make for safety to the middle of the river. In the channels, between the islands in the mouth of the Megna, the height of the Bore is said to exceed twelve feet; and is so terrific in its appearance, and dangerous in its consequences, that no boat will venture to pass at spring-tide.'* These waves may sometimes cause inundations, undermine cliffs, and still more frequently sweep away trees and land animals from low shores, so that they may be carried down, and ultimately imbedded in fluviatile or submarine deposits.

* Rennell, Phil. Trans. 1781.

CHAPTER XXII.

REPRODUCTIVE EFFECTS OF TIDES AND CURRENTS.

DEPOSITING POWER OF TIDAL CURRENTS—SILTING UP OF ESTUARIES DOES NOT COMPENSATE THE LOSS OF LAND ON THE BORDERS OF THE OCEAN—ORIGIN OF SHOALS AND VALLEYS IN THE BED OF THE GERMAN OCEAN—COMPOSITION AND EXTENT OF ITS SAND-BANKS—STRATA DEPOSITED BY CURRENTS IN THE ENGLISH CHANNEL—AT THE MOUTHS OF THE AMAZONS, ORINOCO, AND MISSISSIPPI—WIDE AREA OVER WHICH STRATA MAY BE FORMED BY THIS CAUSE.

Depositing power of tidal currents.—From the facts enumerated in the last chapter, it appears that on the borders of the ocean, currents and tides co-operating with the waves of the sea are most powerful instruments in the destruction and transportation of rocks; and as numerous tributaries discharge their alluvial burden into the channel of one great river, so we find that many rivers deliver their earthy contents to one marine current, to be borne by it to a distance, and deposited in some deep receptacle of the ocean. The current, besides receiving this tribute of sedimentary matter from streams draining the land, acts also itself on the coast, as does a river on the cliffs which bound a valley. Yet the waste of the cliffs by marine currents constitutes on the whole a very insignificant portion of the denudation annually effected by aqueous causes, as I shall point out in the sequel of this chapter (p. 572).

In inland seas, where the tides are insensible, or on those parts of the borders of the ocean where they are feeble, it is scarcely possible to prevent a harbour at a river's mouth from silting up; for a bar of sand or mud is formed at points where the velocity of the turbid river is checked by the sea, or where the river and a marine current neutralise each

other's force. For the current, as we have seen, may, like the river, hold in suspension a large quantity of sediment, or, co-operating with the waves, may cause the progressive motion of a shingle beach in one direction. I have already alluded to the erection of piers and groins at certain places on our southern coast, to arrest the course of the shingle and sand (see p. 536). The immediate effect of these temporary obstacles is to cause a great accumulation of pebbles on one side of the barrier, after which the beach still moves on round the end of the pier at a greater distance from the land. This interference, however, with the natural course or movement of the materials of the beach is often attended with a serious evil, for during storms the waves throw suddenly into the harbour the vast heap of pebbles which have collected for years behind the groin or pier, as happened during a great gale (Jan. 1839) at Dover.

The formation and keeping open of large estuaries are due to the *combined influence* of tidal currents and rivers; for when the tide rises, a large body of water suddenly enters the mouth of the river, where, becoming confined within narrow bounds, while its momentum is not destroyed, it is urged on, and, having to pass through a contracted channel, rises and runs with increased velocity, just as a stream when it reaches the arch of a bridge scarcely large enough to give passage to its waters, rushes with a steep fall through the arch. During the ascent of the tide, a body of fresh water, flowing down from the inland country, is arrested in its course for several hours; and thus a large lake of fresh and brackish water is accumulated, which, when the sea ebbs, is let loose, as on the removal of an artificial sluice or dam. By the force of this retiring water, the alluvial sediment both of the river and of the sea is swept away, and transported to such a distance from the mouth of the estuary, that a small part only can return with the next tide.

It sometimes happens, that during a violent storm a large bar of sand is suddenly made to shift its position, so as to prevent the free influx of the tides, or efflux of river water. Thus about the year 1500 the sands at Bayonne were suddenly thrown across the mouth of the Adour. The river,

flowing back upon itself, soon forced a passage to the northward along the sandy plain of Capbreton, till at last it reached the sea at Boucau, at the distance of *seven leagues* from the point where it had formerly entered. It was not till the year 1579 that the celebrated architect Louis de Foix undertook, at the desire of Henry III., to re-open the ancient channel, which he at last effected with great difficulty.*

In the estuary of the Thames at London, and in the Gironde, the tide rises only for five hours and ebbs seven, and in all estuaries the water requires a longer time to run down than up; so that the preponderating force is always in the direction which tends to keep open a deep and broad passage. But for reasons already explained, there is naturally a tendency in all estuaries to silt up partially, since eddies, and backwaters, and points where opposing streams meet, are very numerous, and constantly change their position.

Many writers have declared that the gain on our eastern coast, since the earliest periods of history, has more than counterbalanced the loss; but they have been at no pains to calculate the amount of loss, and have often forgotten that, while the new acquisitions are manifest, there are rarely any natural monuments to attest the former existence of the land that has been carried away. They have also taken into their account those tracts artificially recovered, which are often of great agricultural importance, and may remain secure, perhaps, for thousands of years, but which are only a few feet above the mean level of the sea, and are therefore exposed to be overflowed again by a small proportion of the force required to move cliffs of considerable height on our shores. If it were true that the area of land annually abandoned by the sea in estuaries were equal to that invaded by it, there would still be no compensation *in kind*.

The tidal current which flows out from the north-west, and which, deflected and confined in the German Ocean, bears against the eastern coast of England, transports, as we have seen, materials of various kinds. Aided by the waves, it undermines and sweeps away the granite, gneiss, trap rocks, and sandstone of Shetland, and removes the

* Nouvelle Chronique de la Ville de Bayonne, pp. 113, 139. 1827.

gravel and loam of the cliffs of Holderness, Norfolk, and Suffolk, which are between twenty and three hundred feet in height, and which waste at various rates of from one foot to six yards annually. It also bears away, in co-operation with the Thames and the tides, the strata of London clay on the coasts of Essex and Sheppey. The sea at the same time consumes the chalk with its flints for many miles continuously on the shores of Kent and Sussex—commits annual ravages on the freshwater beds, capped by a thick covering of chalk-flint gravel, in Hampshire, and continually saps the foundation of the Portland limestone. It receives, besides, during the rainy months, large supplies of pebbles, sand, and mud, which numerous streams from the Grampians, Cheviots, and other chains, send down to the sea. To what regions, then, is all this matter consigned? It is not retained in mechanical suspension by the waters of the ocean, nor does it mix with them in a state of chemical solution,—it is deposited *somewhere*, yet certainly not in the immediate neighbourhood of our shores; for, in that case, there would soon be a cessation of the encroachment of the sea, and large tracts of low land, like Romney Marsh, would almost everywhere encircle our island.

As there is now a depth of water, exceeding thirty feet, in some spots where towns like Dunwich flourished but a few centuries ago, it is clear that the current not only carries far away the materials of the wasted cliffs, but is capable also of keeping clear the bed of the sea to a certain moderate depth.

Origin of shoals and valleys in the bottom of the German Ocean.—To what extent in a downward direction this power of submarine erosion extends, is a question of the highest geological interest, and one respecting which we have at present no very accurate information. The sea between Great Britain and the Continent of Europe has rarely a depth of more than 50 fathoms, and the only part which exceeds 100 fathoms is a narrow channel skirting the western coast of Norway and Sweden, which varies from 200 to 300 fathoms, and attains at one point, near the entrance of the Baltic, the extraordinary depth of 430 fathoms, or 2,580 feet. Some hydrographers are of opinion that even this channel

has been scooped out by a tidal current, but to me it appears more probable that it indicates the original depth of this part of the ocean where fresh sediment has not been thrown down.

Nevertheless, there are some submarine valleys, or long narrow ravines, traversing the shallow parts of the German Ocean, which seem to have been due to a tidal current, capable either of scouring out a channel, or of keeping one clear by not allowing it to become the receptacle of matter drifted towards it from the nearest coast. Of this nature is the depression called the Outer Silver Pits, about 60 miles due east of Flamborough Head, the deepest part of which is about 40 fathoms, or 240 feet. If the Mississippi, with a surface velocity of three miles an hour, can push along sand and gravel at the bottom, and keep open a channel from 150 to 200 feet in depth, a marine current, sometimes flowing at a still greater rate, may well be supposed to excavate or keep clear the Silver Pits. Mr. Murray, in the memoir explanatory of his map of the North Sea, in which he has embodied the results of Captain Hewitt's survey, assumes that this ravine, and also the Inner Silver Pits, near the mouth of the Humber, have been scooped out by the tidal current, whereas the great shoals north and south of the Silver Pits are areas in which drift matter and comminuted shells are constantly heaped up in comparatively tranquil water. The great shoal to the north, called the Dogger Bank, about 60 miles east of the coast of Northumberland, is no less than 200 miles in its longest diameter; it has been compared in size to the whole principality of Wales. In this area there is one tract 75 miles long and 20 broad, nowhere exceeding 15 fathoms in depth, while the shallowest parts were found by Captain Hewitt to be only 42 feet under water, and in one place the wreck of a ship had caused it to be still shallower. South of the Silver Pits there is another vast area of shoals, which we may safely regard as the receptacle both of sediment brought down by rivers and of matter derived from the waste of the British coast. Entire as well as broken shells are dredged up on the Dogger and other banks over which fishermen annually trawl their nets. Currents running sometimes from the north, and sometimes from the south, remove parts of the

banks during heavy gales, causing the sands to shift their position, in which case the strata, when re-deposited, must greatly resemble the so-called crag of Norfolk and Suffolk. Nor can there fail, in the course of ages, to be spots where some of the unconsolidated older tertiary formations, such, for example, as the Bagshot sand and London clay, will be denuded with as much facility as the modern sand-banks; such denudation would inevitably take place during oscillations in the level of the bottom of the sea, like those which we know to have occurred during and since the Glacial epoch. Whenever the sea scooped out such channels in the ancient strata, fossil shells of extinct species would be mingled with recent ones, and both the one and the other would often be more or less rolled. As the bones also of the elephant and other extinct mammalia are occasionally dredged up with oysters attached to them, from the bed of the sea between Suffolk and the Netherlands, such fossil bones would be occasionally included in the new formations. The chief difference in character between the Pliocene and modern strata will consist in the intermixture in the latter of works of art together with the bones of man; monuments of hundreds, nay thousands, of wrecked vessels, which in the last twenty centuries have sunk on these banks, and so impeded for a time the free passage over them of shelly sand, as to produce shoals reaching within thirty feet of the surface.

So great is the quantity of mud held in suspension by the tidal current on our shores, that it is found useful artificially to introduce the water into certain lands reclaimed from the sea and which are below the level of high tide; and by repeating this operation, which is called 'warping,' for two or three years, considerable tracts have been raised, in the estuary of the Humber, to the height of about six feet above their former level. If a current, charged with such materials, meets with deep depressions in the bed of the ocean, it must often fill them up; just as a river, when it meets with a lake in its course, fills it gradually with sediment.

Comparative efficacy of rivers and currents as transporting and denuding agents.—I have said (p. 566) that the action of

the waves and currents on sea-cliffs, or their power to remove matter from above to below the sea-level, is insignificant in comparison with the power of rivers to perform the same task. As an illustration we may take the coast of Holderness, described in Chap. xx. (p. 514). It is composed, as we have seen, of very destructible materials, is thirty-six miles long, and its average height may be taken at forty feet. As it has wasted away at the rate of two and a quarter yards annually, for a long period, it will be found on calculation that the quantity of matter thrown down into the sea every year, and removed by the current, amounts to 51,321,600 cubic feet. It has been shown that the united Ganges and Brahmapootra carry down to the Bay of Bengal 40,000,000,000 cubic feet of solid matter every year, so that their transporting power is no less than 780 times greater than that of the sea on the coast above mentioned; and in order to produce a result equal to that of the two Indian rivers, we must have a line of wasting coast, like that of Holderness, nearly 28,000 miles in length, or longer than the entire circumference of the globe by above 3,000 miles. The reason of so great a difference in the results may be understood when we reflect that the operations of the ocean are limited to a single line of cliff surrounding a large area, whereas great rivers with their tributaries, and the mountain torrents which flow into them, act simultaneously on a length of bank almost indefinite.

Nevertheless we are by no means entitled to infer that the denuding force of the great ocean is a geological cause of small efficacy, or inferior to that of rivers. Its chief influence is exerted at moderate depths below the surface, on all those areas which are slowly rising, or are attempting, as it were, to rise above the sea. From data hitherto obtained respecting subterranean movements, we can scarcely speculate on an average rate of upheaval of more than two or three feet in a century. An elevation to this amount is taking place in Scandinavia, and probably in many submarine areas as vast as those which we know to be sinking from the proofs derived from circular lagoon islands or coral atolls.*

* See the last chapter in Vol. II.

Suppose strata as destructible as the greater part of the Tertiary, Cretaceous, and Wealden deposits of the British Isles, or the coal-measures or mud-stones of the Silurian periods, to be thus slowly upheaved, how readily might they all be swept away by waves and currents in an open sea! How entirely might each stratum disappear as it was brought up successively and exposed to the breakers! Shoals of wide extent might be produced, but it is difficult to conceive how any continent could ever be formed under such circumstances. Were it not indeed for the hardness and toughness of some limestones and of many crystalline and volcanic rocks which are often capable of resisting the action of the waves, few lands might ever emerge from the midst of an open sea.

Arrangement of materials in current deposits and their wide diffusion.—It has been ascertained by soundings in all parts of the world, that where new deposits are taking place in the sea, coarse sand and small pebbles commonly occur near the shore, while farther from land, and in deeper water, finer sand and broken shells are spread out over the bottom. Still farther out, the finest mud and ooze are alone met with. Mr. Austen observes that this rule holds good in every part of the English Channel examined by him. He also informs us, that where the tidal current runs rapidly in what is called 'races,' where surface undulations are perceived in the calmest weather, over deep banks, the discoloration of the water does not arise from the power of such a current to disturb the bottom at a depth of 40 to 80 fathoms, as some have supposed. In these cases, a column of water, sometimes 500 feet in height, is moving onwards with the tide clear and transparent above, while the lower portion holds fine sediment in suspension (a fact ascertained by soundings), when suddenly it impinges upon a bank, and its height is reduced to 300 feet. It is thus made to boil up and flow off at the surface, a process which forces up the lower strata of water charged with fine particles of mud, which in their passage from the coast had gradually sunk to a depth of 300 feet or more.*

One characteristic effect of the action of currents is, the

* Robt. A. C. Austen, Quart. Journ. Geol. Soc. vol. vi. p. 76.

immense extent over which they may be the means of diffusing homogeneous mixtures. Even off coasts where there are no large rivers, they may still have the power of spreading far and wide over the bottom of the ocean, not only sand and pebbles, but the finest mud. Thus for *several thousand miles* along the western coast of South America, comprising the larger parts of Peru and Chili, there is a perpetual rolling of shingle along the shore, part of which, as Mr. Darwin has shown, is incessantly reduced to the finest mud by the waves, and swept into the depths of the Pacific by the tides and currents. The same author, however, has remarked that, notwithstanding the great force of the waves on that shore, all rocks 60 feet under water are covered by sea-weed, showing that the bed of the sea is not denuded at that depth, the effect of the winds being comparatively superficial.

In regard to the distribution of sediment by currents it may be observed, that the rate of subsidence of the finer mud carried down by every great river into the ocean, or of that caused by the rolling of the waves upon a shore, must be extremely slow; for the more minute the separate particles of mud, the more slowly will they sink to the bottom, and the sooner will they acquire what is called their terminal velocity. It is well known that a solid body, descending through a resisting medium, falls by the force of gravity, which is constant, but its motion is resisted by the medium more and more as its velocity increases, until the resistance becomes sufficient to counteract the further increase of velocity. For example, a leaden ball, one inch in diameter, falling through air of density as at the earth's surface, will never acquire greater velocity than 260 feet per second, and, in water, its greatest velocity will be 8 feet 6 inches per second. If the diameter of the ball were $\frac{1}{100}$ of an inch, the terminal velocities in air would be 26 feet, and in water ·86 of a foot per second.

Now, every chemist is familiar with the fact that minute particles descend with extreme slowness through water, the extent of their surface being very great in proportion to their weight, and the resistance of the fluid depending on the amount of surface. A precipitate of sulphate of baryta, for

example, will sometimes require more than five or six hours to subside one inch ;* while oxalate and phosphate of lime require nearly an hour to subside about an inch and a half and two inches respectively,† so exceedingly small are the particles of which these substances consist.

When we recollect that the depth of the ocean is supposed frequently to exceed three miles, and that currents run through different parts of that ocean at the rate of four miles an hour, and when at the same time we consider that some fine mud carried away from the mouths of rivers and from sea-beaches, where there is a heavy surf, as well as the impalpable powder showered down by volcanos, may subside at the rate of only an inch per hour, we shall be prepared to find examples of the transportation of sediment over areas of indefinite extent.

* On the authority of Mr. Faraday. † On the authority of Mr. R. Phillips.

CHAPTER XXIII.

IGNEOUS CAUSES.

CHANGES OF THE INORGANIC WORLD, CONTINUED—IGNEOUS CAUSES—DIVISION OF THE SUBJECT—DISTINCT VOLCANIC REGIONS—REGION OF THE ANDES—SYSTEM OF VOLCANOS EXTENDING FROM THE ALEUTIAN ISLES TO THE MOLUCCA AND SUNDA ISLANDS—POLYNESIAN ARCHIPELAGO—VOLCANIC REGION EXTENDING FROM CENTRAL ASIA TO THE AZORES—TRADITION OF DELUGES ON THE SHORES OF THE BOSPHORUS, HELLESPONT, AND GRECIAN ISLES—PERIODICAL ALTERNATION OF EARTHQUAKES IN SYRIA AND SOUTHERN ITALY—WESTERN LIMITS OF THE EUROPEAN REGION—EARTHQUAKES RARER AND MORE FEEBLE AS WE RECEDE FROM THE CENTRES OF VOLCANIC ACTION—EXTINCT VOLCANOS NOT TO BE INCLUDED IN LINES OF ACTIVE VENTS.

We have hitherto considered the changes wrought, since the times of history and tradition, by the continued action of aqueous causes on the earth's surface; and we have next to examine those resulting from igneous agency. As the rivers and springs on the land, and the tides and currents in the sea, have, with some slight modifications, been fixed and constant to certain localities from the earliest periods of which we have any records, so the volcano and the earthquake have, with few exceptions, continued, during the same lapse of time, to disturb the same regions. But as there are signs, on almost every part of our continent, of great power having been exerted by running water on the surface of the land, and by waves, tides, and currents on cliffs bordering the sea, where, in modern times, no rivers have excavated, and no waves or tidal currents undermined—so we find signs of volcanic vents and violent subterranean movements in places where the action of fire or internal heat has long been dormant. We can explain why the intensity of the force of aqueous causes should be developed in succession in different districts. Currents, for example, tides, and the waves of the

sea, cannot destroy coasts, shape out or silt up estuaries, break through isthmuses, and annihilate islands, form shoals in one place, and remove them from another, without the direction and position of their destroying and transporting power becoming transferred to new localities. Neither can the relative levels of the earth's crust, above and beneath the waters, vary from time to time, as they are admitted to have varied at former periods, and as it will be demonstrated that they still do, without the continents being, in the course of ages, modified, and even entirely altered, in their external configuration. Such events must clearly be accompanied by a complete change in the volume, velocity, and direction of the streams and land floods to which certain regions give passage. That we should find, therefore, cliffs where the sea once committed ravages, and from which it has now retired—estuaries where high tides once rose, but which are now dried up—valleys hollowed out by water, where no streams now flow, is no more than we should expect;—these and similar phenomena are the necessary consequences of physical causes now in operation; and if there be no instability in the laws of nature, similar fluctuations must recur again and again in time to come.

But, however natural it may be that the force of running water in numerous valleys, and of tides and currents in many tracts of the sea, should now be *spent*, it is by no means so easy to explain why the violence of the earthquake and the fire of the volcano should also have become locally extinct at successive periods. We can look back to the time when the marine strata, whereon the great mass of Etna rests, had no existence; and that time is extremely modern in the earth's history. This alone affords ground for anticipating that the eruptions of Etna will one day cease.

> Nec quæ sulfureis ardet fornacibus Ætna
> Ignea semper erit, *neque enim fuit ignea semper,*
> (Ovid, *Metam.* lib. xv. 340)

are the memorable words which are put into the mouth of Pythagoras by the Roman poet, and they are followed by speculations as to the cause of volcanic vents shifting their

positions. Whatever doubts the philosopher expresses as to the nature of these causes, it is assumed as incontrovertible that the points of eruption will hereafter vary, *because they have formerly done so*; a principle of reasoning which, as I have endeavoured to show in former chapters, has been too much set at nought by some of the earlier schools of geology, which refused to conclude that great revolutions in the earth's surface are now in progress, or that they will take place hereafter, *because* they have often been repeated in former ages.

Division of the subject.—Volcanic action may be defined to be 'the influence exerted by the heated interior of the earth on its external covering.' If we adopt this definition, without connecting it, as Humboldt has done, with the theory of secular refrigeration, or the cooling down of an original heated and fluid nucleus, we may then class under a general head all the subterranean phenomena, whether of volcanos, or earthquakes, and those insensible movements of the land, by which, as will afterwards appear, large districts may be depressed or elevated, without convulsions. According to this view, I shall consider, first, the volcano; secondly, the earthquake; thirdly, the rising or sinking of land in countries where there are no volcanos or earthquakes; fourthly, the probable *causes* of the different changes which result from subterranean agency.

It is a very general opinion that earthquakes and volcanos have a common origin; for both are confined to certain regions, although the subterranean movements are as a rule by no means most violent in the immediate proximity of volcanic vents, especially if the discharge of aeriform fluids and melted rock is made constantly from the same crater. But as there are particular regions, to which both the points of eruption and the movements of great earthquakes are confined, I shall begin by tracing out the geographical boundaries of some of these, that the reader may be aware of the magnificent scale on which the agency of subterranean fire is now simultaneously developed. Over the whole of the vast tracts alluded to, active volcanic vents are distributed at intervals, and most commonly arranged in a linear direction.

Throughout the intermediate spaces there is often abundant evidence that the subterranean fire is at work continuously, for the ground is convulsed from time to time by earthquakes; gaseous vapours, especially carbonic acid gas, are disengaged plentifully from the soil; springs often issue at a very high temperature, and their waters are usually impregnated with the same mineral matters as are discharged by volcanos during eruptions.

When a volcano is isolated like Etna, it is supposed to have opened a communication with the interior by a star-shaped fissure, whereas vents which are linearly arranged imply a long line of dislocation in the earth's crust, analogous to those great lines of rending, upheaval, or dislocation to which the axes of mountain-chains are due. We know that when the side of a great volcanic cone is rent, an open and straight fissure is sometimes formed many miles in length, as was the case on Etna in 1669, when a rent twelve miles long was produced, at the bottom of which incandescent lava was seen. Here and there along the line of such a rent, cones of eruption are thrown up in succession at points where the gaseous matter obtains the freest access to the surface, and has power to force up lava and scoriæ. What is here displayed on a small scale is exhibited in grander dimensions where active volcanos form chains thousands of miles in length. The distances to which trap dikes or the lava which once filled the lower parts of vertical rents can sometimes be traced, is another monument of the same kind of action. Some of the dikes in the north-east of England—Yorkshire, Durham, and Northumberland—for instance, may be followed from 20 to 60 miles in nearly straight lines, and were no doubt at some remote period connected with fissures extending upwards perhaps even to what was then the surface of the earth's crust, whether covered by the sea or atmosphere. M. Alexis Perrey, in his History of Earthquakes, has shown that violent subterranean movements are most frequent along the axes of mountain-chains.

VOLCANIC REGIONS.

Region of the Andes of South America.—Of the great volcanic regions, that of the Andes of South America is one of the best defined; it affords an illustration of the linear arrangement already alluded to, of which there is no good exemplification in Europe, where the most active volcanic vents are isolated. If we turn first to that part of the Cordillera which extends from lat. 2° N. or northward of Quito, to lat. 43° S. or southward of Chili, we have, in a space comprehending forty-five degrees of latitude, an alternation on a grand scale of districts of active with those of extinct volcanos, or which, if not spent, have at least been dormant for the last three centuries. How long an interval of rest may entitle us to consider a volcano as entirely extinct is not easily determined; but we know that in Ischia there intervened between two consecutive eruptions a pause of seventeen centuries; and the discovery of America is an event of far too recent a date to allow us even to conjecture whether different portions of the Andes, nearly the whole of which are subject to earthquakes, may not experience alternately a cessation and renewal of eruptions. Nor does the linear series seem to end even with the southern limits of the Cordillera, for we can scarcely doubt that the Fuegian volcanos in lat. 54° 30′ S., and those of South Shetland, lat. 61° S., belong to the same chain.

The principal line of active vents which have been seen in eruption in the Andes extends from lat. 43° 28′ S.; or, from Yantales, opposite the Isle of Chiloe, to Coquimbo, in lat. 30° S.; to these thirteen degrees of latitude succeed more than eight degrees, in which no recent volcanic eruptions have been observed. We then come to the volcanos of Bolivia and Peru, reaching six degrees from S. to N., or from lat. 21° S. to lat. 15° S. Between the Peruvian volcanos and those of Quito, another space intervenes of no less than fourteen degrees of latitude, said to be free from volcanic action so far as yet known. The volcanos of Quito then succeed, beginning about 100 geographical miles south of

the equator, and continuing for about 130 miles north of it, when there occurs another undisturbed interval of more than six degrees of latitude, after which we arrive at the volcanos of Guatemala or Central America, north of the Isthmus of Panama.*

Having thus traced out the line from south to north, I may first state, in regard to the numerous vents of Chili, that the volcanos of Yantales and Osorno were in eruption during the great earthquake of 1835, at the same moment that the land was shaken in Chiloe, and in some parts of the Chilian coast permanently upheaved; whilst at Juan Fernandez, at the distance of no less than 720 geographical miles from Yantales, an eruption took place beneath the sea. We have thus proofs of a great subterranean disturbance extending simultaneously over an area about 900 miles (60 to a degree) north and south, and in one part at least 600 due east and west. Some of the volcanos of Chili are of great height, as that of Antuco, in lat. 37° 40′ S., the summit of which is at least 16,000 feet above the sea. From the flanks of this volcano, at a great height, immense currents of lava have issued, one of which flowed in the year 1828. This event is said to be an exception to the general rule; few volcanos in the Andes, and none of those in Quito, having been seen in modern times to pour out lava, but having merely ejected vapour or scoriæ.

Both the basaltic (or augitic) lavas, and those of the felspathic class, occur in Chili and other parts of the Andes; but the volcanic rocks of the felspathic family are said by Von Buch to be generally not trachyte, but a rock which has been called andesite, or a mixture of augite and albite. The last-mentioned mineral contains soda instead of the potash found in common felspar.

The volcano of Rancagua, lat. 34° 15′ S., is said to be always throwing out ashes and vapours like Stromboli, a proof of the permanently heated state of certain parts of the interior of the earth below. A year rarely passes in Chili without some slight shocks of earthquakes, and in certain districts not a month. Those shocks which come from the

* See Von Buch's Description of Canary Islands (Paris, ed. 1836) for a valuable sketch of the principal volcanos of the globe.

side of the ocean are the most violent, and the same is said to be the case in Peru. The town of Copiapo was laid waste by this terrible scourge in the years 1773, 1796, and 1819, or in both cases after regular intervals of twenty-three years. There have, however, been other shocks in that country in the periods intervening between the dates above mentioned, although probably all less severe, at least on the exact site of Copiapo. The evidence against a regular recurrence of volcanic convulsions at stated periods is so strong as a general fact, that we must be on our guard against attaching too much importance to a few striking but probably accidental coincidences. Among these last might be adduced the case of Lima, violently shaken by an earthquake on the 17th of June, 1578, and again on the very same day, 1678; or the eruptions of Coseguina in the years 1709 and 1809, which are the only two recorded of that volcano previous to that of 1835.*

Of the permanent upheaval of land after earthquakes in Chili, I shall have occasion to speak in the next chapter, when it will also be seen that great shocks often coincide with eruptions, either submarine, or from the cones of the Andes, showing the connection between the force which elevates continents with that which causes volcanic outbursts.†

The space between Chili and Peru, in which no volcanic action has been observed, is 150 nautical leagues from south to north. It is, however, as Von Buch observes, that part of the Andes which is least known, being thinly peopled, and in some parts entirely desert. The volcanos of Peru rise from a lofty platform to vast heights from 17,000 to 20,000 feet above the level of the sea. The lava which has issued from Viejo, lat. 16° 55′ S., accompanied by pumice, is composed of a mixture of crystals of albitic felspar, hornblende, and mica, a rock which has been considered as one of the varieties of andesite. Some tremendous earthquakes which have visited Peru in modern times will be mentioned in a subsequent chapter.

The volcanos of Quito, occurring between the second

* Darwin, Geol. Trans. 2nd series, vol. v. p. 612. † Ibid. p. 606.

degree of south and the third degree of north latitude, rise to vast elevations above the sea, many of them being between 14,000 and 18,000 feet high. The Indians of Lican have a tradition that the mountain called L'Altar, or Capac Urcu, which means 'the chief,' was once the highest of those near the equator, being higher than Chimborazo; but in the reign of Ouainia Abomatha, before the discovery of America, a prodigious eruption took place, which lasted eight years, and broke it down. The fragments of trachyte, says M. Boussingault, which once formed the conical summit of this celebrated mountain, are at this day spread over the plain.* Cotopaxi is the most lofty of all the South American volcanos which have been in a state of activity in modern times, its height being 18,858 feet; and its eruptions have been more frequent and destructive than those of any other mountain. It is a perfect cone, usually covered with an enormous bed of snow, which has, however, been sometimes melted suddenly during an eruption; as in January 1803, for example, when the snows were dissolved in one night.

Deluges are often caused in the Andes by the liquefaction of great masses of snow, and sometimes by the rending open, during earthquakes, of subterranean cavities filled with water. In these inundations fine volcanic sand, loose stones, and other materials which the water meets with in its descent, are swept away, and a vast quantity of mud, called 'moya,' is thus formed and carried down into the lower regions. Mud derived from this source descended, in 1797, from the sides of Tunguragua in Quito, and filled valleys a thousand feet wide to the depth of six hundred feet, damming up rivers and causing lakes. In these currents and lakes of moya, thousands of small fish are sometimes enveloped, which, according to Humboldt, have lived and multiplied in subterranean cavities. So great a quantity of these fish were ejected from the volcano of Imbaburu in 1691, that fevers, which prevailed at the period, were attributed to the effluvia arising from the putrid animal matter.

In Quito, many important revolutions in the physical features of the country are said to have resulted, within the

* Bull. de la Soc. Géol. de France, 2nd Sér. tom. vi. p. 55.

memory of man, from the earthquakes by which it has been convulsed. M. Boussingault declares his belief, that if a full register had been kept of all the convulsions experienced here and in other populous districts of the Andes, it would be found that the trembling of the earth had been incessant. The frequency of the movement, he thinks, is not due to volcanic explosions, but to the continual falling in of masses of rock which have been fractured and upheaved in a solid form at a comparatively recent epoch; but a longer series of observations would be requisite to confirm this opinion. According to the same author, the height of several mountains of the Andes has diminished in modern times.*

The great crest or cordillera of the Andes is depressed at the Isthmus of Panama to about 1,000 feet above the sea-level, and the watershed between the two seas near the Gulf of San Miguel is only 150 feet high. What some geographers regard as a continuation of that chain in Central America lies to the east of a series of volcanos, many of which are active, in the provinces of Pasto, Popayan, and Guatemala. Coseguina, on the south side of the Gulf of Fonseca, was in eruption in January 1835, and some of its ashes fell at Truxillo, on the shores of the Gulf of Mexico. What is still more remarkable, on the same day, at Kingston in Jamaica, the same shower of ashes fell, having been carried by an upper counter-current against the regular east wind which was then blowing. Kingston is about 700 miles distant from Coseguina, and these ashes must have been more than four days in the air, having travelled 170 miles a day. Eight leagues to the southward of the crater, the ashes covered the ground to the depth of three yards and a half, destroying the woods and dwellings. Thousands of cattle perished, their bodies being in many instances one mass of scorched flesh. Deer and other wild animals sought the towns for protection; many birds and quadrupeds were found suffocated in the ashes, and the neighbouring streams were strewed with dead fish.† Such facts throw light on geological monuments, for in the ashes thrown out at remote

* Bull. de la Soc. Géol. de France, tom. vi. p. 56.

† Caldcleugh, Phil. Trans. 1836, p. 27.

periods from the volcanos of Auvergne, now extinct, we find the bones and skeletons of lost species of quadrupeds.

Mexico.—The great volcanic chain, after having thus pursued its course for several thousand miles from south to north, sends off a branch in a new direction in Mexico, in the parallel of the city of that name, and is prolonged in a great platform, between the eighteenth and twenty-second degrees of north latitude. Five active volcanos traverse Mexico from west to east—Tuxtla, Orizaba, Popocatepetl, Jorullo, and Colima. Jorullo, which is in the centre of the great platform, is no less than 120 miles from the nearest ocean—an important circumstance, as showing that the proximity of the sea is not a necessary condition, although certainly a very general characteristic, of the position of active volcanos. The extraordinary eruption of this mountain, in 1759, will be described in the sequel. If the line which connects these five vents be prolonged in a westerly direction, it cuts the volcanic group of islands called the Isles of Revillagigedo, in the Pacific.

To the north of Mexico there are said to be three, or according to some, five volcanos in the peninsula of California; and a volcano is reported to have been in eruption on the N.W. coast of America, near the Columbia River, lat. 45° 37′ N.

West Indies.—To return to the Andes of Quito, Von Buch was inclined to believe that if we were better acquainted with the region to the east of the Madalena, and with New Granada and the Caraccas, we might find the volcanic chain of the Andes to be connected with that of the West Indian, or Caribbee Islands. The truth of this conjecture has almost been set at rest by the eruption, in 1848, of the volcano of Zamba in New Granada, at the mouth of the river Madalena.*

Of the West Indian Islands there are two parallel series, the one to the west, which are all volcanic, and which rise to the height of several thousand feet; the other to the east, for the most part composed of calcareous rocks, and of moderate height. In the former or volcanic series, are Granada, St.

* Comptes Rendus, 1849, vol. xxix. p. 531.

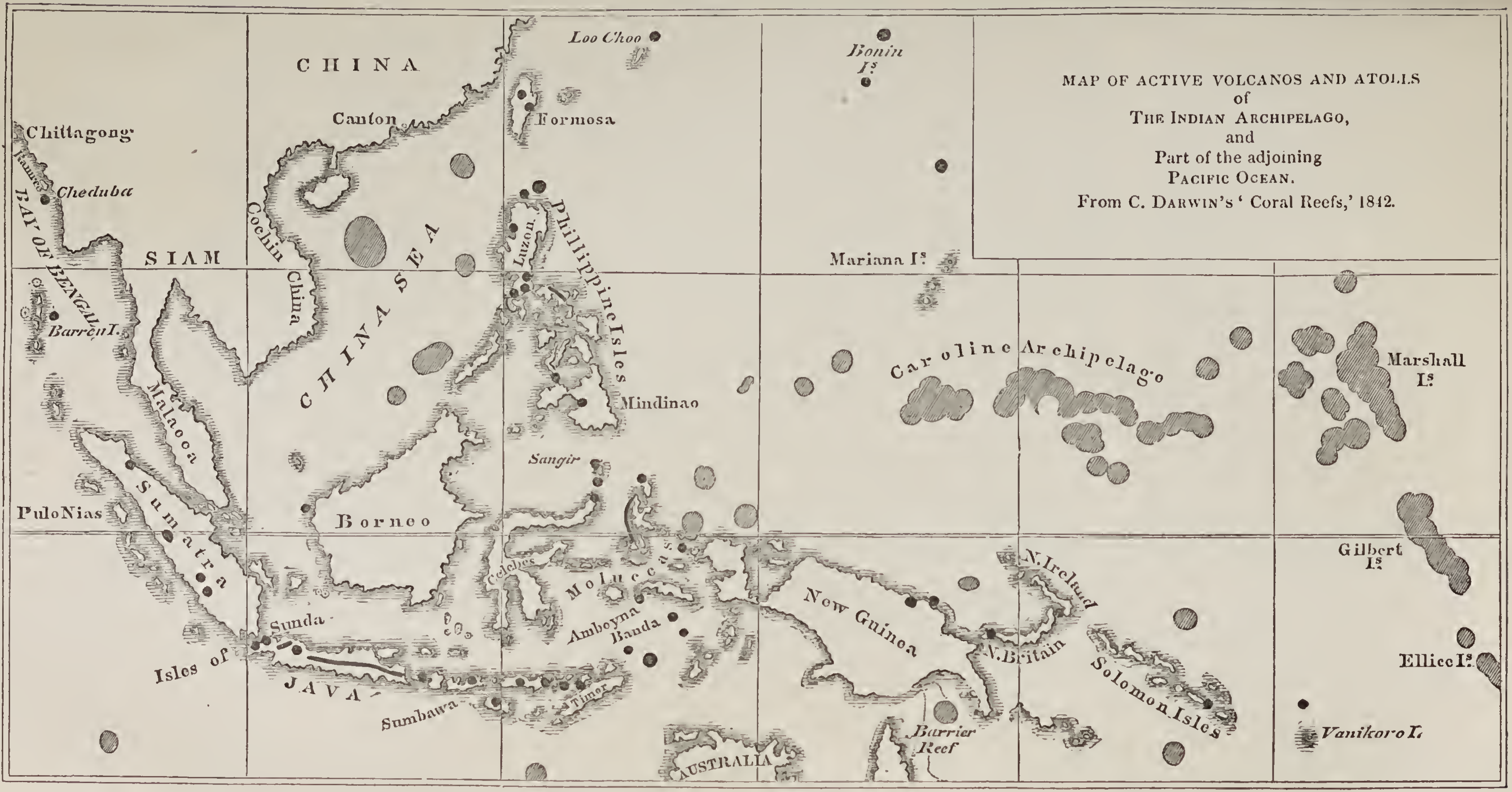
Vincent, St. Lucia, Martinique, Dominica, Guadaloupe, Montserrat, Nevis, and St. Eustace. In the calcareous chain are Tobago, Barbadoes, Marie Galante, Grandeterre, Desirade, Antigua, Barbuda, St. Bartholomew, and St. Martin. The most considerable eruptions in modern times have been those of St. Vincent. Great earthquakes have agitated St. Domingo, as will be seen in the thirtieth chapter.

I have before mentioned (p. 459) the violent earthquake which in 1812 convulsed the valley of the Mississippi at New Madrid for the space of 300 miles in length, of which more will be said in the twenty-eighth chapter. This happened exactly at the same time as the great earthquake of Caraccas, so that it is possible that these two points are parts of one subterranean volcanic region. The Island of Jamaica, with a tract of the contiguous sea, has often experienced tremendous shocks; and these are frequent along a line extending from Jamaica to St. Domingo and Porto Rico.

Thus it will be seen that, without taking account of the West Indian and Mexican branches, a linear train of volcanos and tracts shaken by earthquakes may be traced from the Island of Chiloe and opposite coast to Mexico, or even perhaps to the mouth of the Columbia River— a distance upon the whole as great as from the pole to the equator. In regard to the western limits of the region, they lie deep beneath the waves of the Pacific, and must continue unknown to us. On the east they are not prolonged to a great distance, except where they include the West Indian Islands; for there seem to be no indications of volcanic eruptions in Buenos Ayres, Brazil, and the United States of North America east of the Rocky Mountains. In California, Oregon, and north-west America, ten or twelve volcanos are mentioned.

Volcanic region from the Aleutian Isles to the Moluccas and Isles of Sunda.—On a scale which equals or surpasses that of the Andes, is another line of volcanic action, which commences, on the north, with the Aleutian Isles in Russian America, and extends, first in a westerly direction for nearly 200 geographical miles, and then southwards, with a few interruptions, throughout a space of between sixty and seventy

Fig. 66.



Active volcanos. Trains of active volcanos. Areas of subsidence containing atolls or coral islands with lagoons.

degrees of latitude to the Moluccas, where it sends off a branch to the south-east, while the principal train continues westerly through Sumbawa and Java to Sumatra, and then in a north-westerly direction to the Bay of Bengal.* This volcanic line, observes Von Buch, may be said to follow throughout its course the external border of the continent of Asia ; while the branch which has been alluded to as striking south-east from the Moluccas, passes from New Guinea to New Zealand, conforming, though somewhat rudely, to the outline of Australia.†

The connection, however, of the New Guinea volcanos with the line in Java (as laid down in Von Buch's map) is not clearly made out. By consulting Darwin's map of coral reefs and active volcanos,‡ the reader will see that we might almost with equal propriety include the Mariana and Bonin volcanos in a band with New Guinea. Or if we allow so much latitude in framing zones of volcanic action, we must also suppose the New Hebrides, Solomon Isles, and New Ireland (see map fig. 65, p. 587) to constitute one line with the New Hebrides, which lie to the south of the same map.

The northern extremity of the volcanic region of Asia, as described by Von Buch, is on the borders of Cook's Inlet, north-east of the Peninsula of Alaska, where one volcano, in about the sixtieth degree of latitude, is said to be 14,000 feet high. In Alaska itself are cones of vast height, which have been seen in eruption, and which are covered for two-thirds of their height downwards with perpetual snow. The summit of the loftiest peak is truncated, and is said to have fallen in during an eruption in 1786. From Alaska the line is continued through the Aleutian or Fox Islands to Kamtschatka. In the Aleutian Archipelago eruptions are frequent, and about thirty miles to the north of Unalaska, near the Isle of Umnack, a new island was formed in 1796. It was first observed after a storm, at a point in the sea from which a column of smoke had been seen to rise. Flames then issued from the new islet which illuminated the country for ten miles round;

* See map of volcanic lines in Von Buch's work on the Canaries.

† Von Buch, ibid. 409.

‡ Darwin, Structure and Distrib. of Coral Reefs, &c. London, 1842. In the annexed map, fig. 65, I have copied with permission a small part of the valuable map accompanying that work.

a frightful earthquake shook the new-formed cone, and showers of stones were thrown as far as Umnack. The eruption continued for several months, and eight years afterwards, in 1804, when it was explored by some hunters, the soil was so hot in some places that they could not walk on it. According to Langsdorf and others, this new island, which is now several thousand feet high and two or three miles in circumference, has been continually found to have increased in size when successively visited by different travellers; but we have no accurate means of determining how much of its growth, if any, has been due to upheaval, or how far it has been exclusively formed by the ejection of ashes and streams of lava. It seems, however, to be well attested that earthquakes of the most terrific description agitate and alter the bed of the sea and surface of the land throughout this tract.

The line is continued in the southern extremity of the Peninsula of Kamtschatka, where, according to Dittmar, there are twelve active and twenty-six extinct volcanic cones. The largest and most active of these is Klutschew, lat. 56° 3′ N., which rises at once from the sea to the prodigious height of 15,000 feet. Within 700 feet of the summit, Erman saw, in 1829, a current of lava, emitting a vivid light, flow down the north-west side to the foot of the cone. Large quantities of ice and snow opposed for a time a barrier to the lava, until at length the fiery torrent overcame, by its heat and pressure, this obstacle, and poured down the mountain side with a frightful noise, which was heard for a distance of more than fifty miles.*

Mont Blanc is 15,760 feet high, but a flow of lava from its summit to the base in the valley of Chamouni would give a very inadequate idea of the descent of the Kamtschatka current, because Chamouni is 3,500 feet above the level of the sea.†

The Kurile chain of islands constitutes the prolongation of the Kamtschatka range, where a train of volcanic mountains, nine of which are known to have been in eruption, trends in a

* Von Buch, Descrip. des Iles Canar. p. 450, who cites Erman and others.

† For later eruptions in the Alaska, Kamtschatka, and Kurile region, see Alexis Perrey, Soc. Imp. de Lyon, 1863.

southerly direction. The line is then continued to the south-west in the great island of Jesso, and again in Nipon, the principal of the Japanese group. It then extends by Loo Choo and Formosa to the Philippine Islands, and thence by Sangir and the north-eastern extremity of Celebes to the Moluccas (see map, fig. 65). Afterwards it passes westward through Sumbawa to Java.

There are said to be thirty-eight considerable volcanos in Java, some of which are more than 10,000 feet high. They are remarkable for the quantity of sulphur and sulphureous vapours which they discharge. They rarely emit lava, but rivers of mud issue from them, like the moya of the Andes of Quito. The memorable eruption of Galongoon, in 1822, will be described in the twenty-sixth chapter. The crater of Taschem, at the eastern extremity of Java, contains a lake strongly impregnated with sulphuric acid, a quarter of a mile long, from which a river of acid water issues, which supports no living creature, nor can fish live in the sea near its confluence. There is an extinct crater near Batur, called Guevo Upas, or the Valley of Poison, about half a mile in circumference, which is justly an object of terror to the inhabitants of the country. Every living being which penetrates into this valley falls down dead, and the soil is covered with the carcases of tigers, deer, birds, and even the bones of men; all killed by the abundant emanations of carbonic acid gas, by which the bottom of the valley is filled.

In another crater in this land of wonders, near the volcano of Talaga Bodas, we learn from Mr. Reinwardt, that the sulphureous exhalations have killed tigers, birds, and innumerable insects; and the soft parts of these animals, such as fibres, muscles, nails, hair, and skin, are very well preserved, while the bones are corroded, and entirely destroyed.

We learn from observations made in 1844, by Mr. Jukes, that a recent tertiary formation composed of limestone and resembling the coral rock of a fringing reef, clings to the flanks of all the volcanic islands from the east end of Timor to the west end of Java. These modern calcareous strata are often white and chalk-like, sometimes 1,000 feet and upwards above the sea, regularly stratified in thick horizontal

beds, and they show that there has been a general elevation of these islands at a comparatively modern period.*

The same linear arrangement which is observed in Java holds good in the volcanos of Sumatra, some of which are of great height, as Berapi, which is more than 12,000 feet above the sea, and is continually emitting vapour. Hot springs are abundant at its base. The volcanic line then inclines slightly to the north-west, and points to Barren Island, lat. 12° 15′ N., in the Bay of Bengal; a volcano often observed to emit smoke and vapours, and from which lava has proceeded since 1780 (see below, Chap. xxvii.) The volcanic train then extends, according to Dr. Macclelland, to the island of Narcondam, lat. 13° 22′ N., which is a cone seven or eight hundred feet high, rising from deep water, and said to present signs of lava currents descending from the crater to the base. Afterwards the train stretches in the same direction to the volcanic island of Ramree, about lat. 19° N., and the adjoining island of Cheduba, which is represented in old charts as a burning mountain. Thus we arrive at the Chittagong coast, which in 1672 was convulsed by a tremendous earthquake (see Chap. xxx.)†

To enumerate all the volcanic regions of the Indian and Pacific oceans would lead me far beyond the proper limits of this treatise; but it will appear in the last chapter of this work, when coral reefs are treated of, that the islands of the Pacific consist alternately of linear groups of two classes, the one lofty, and containing active volcanos, and marine strata above the sea-level, and which have been undergoing upheaval in modern times; the other very low, consisting of reefs of coral, usually with lagoons in their centres, and in which there is evidence of a gradual subsidence of the ground. The extent and direction of these parallel volcanic bands has been depicted with great care by Darwin in his map before cited (p. 587).

The most remarkable theatre of volcanic activity in the Northern Pacific—or, perhaps, in the whole world—occurs

* Paper read at meeting of Brit. Assoc. Southampton, Sept. 1846.

† Macclelland, Report on Coal and Min. Resources of India. Calcutta, 1838.

in the Sandwich Islands, which have been admirably treated of in a work published by Mr. Dana in 1849.*

Volcanic region from Central Asia to the Azores.—Another great region of subterranean disturbance is that which has been imagined to extend through a large part of Central Asia to the Azores, that is to say, from China and Tartary through Lake Aral and the Caspian to the Caucasus and the countries bordering the Black Sea, then again through part of Asia Minor to Syria, and westward to the Grecian Islands, Greece, Naples, Sicily, the southern part of Spain, Portugal, and the Azores. The breaks in this supposed continuous series of volcanic disturbances are of such extent that the connection as a linear group cannot be insisted on, but it may be useful in helping us to remember the geographical limits within which certain volcanos and earthquakes of historical date have been witnessed. Respecting the eastern extremity of this line in China, we have little information, but many violent earthquakes are known to have occurred there. The volcano said to have been in eruption in the seventh century in Central Tartary is situated on the northern declivity of the Celestial Mountains, not far distant from the large lake called Issikoul; and Humboldt mentions other vents and solfataras in the same quarter, which are all worthy of notice, as being far more distant from the ocean (260 geographical miles) than any other known points of eruption on the globe.

We find on the western shores of the Caspian, in the country round Baku, a tract called the Field of Fire, which continually emits inflammable gas, while springs of naphtha and petroleum occur in the same vicinity, as also mud volcanos (see Chap. xxvii.) Syria and Palestine abound in volcanic appearances, and very extensive areas have been shaken, at different periods, with great destruction of cities and loss of lives. Continual mention is made in history of the ravages committed by earthquakes in Sidon, Tyre, Berytus, Laodicea, and Antioch, and in the Island of Cyprus.

* Geology of the American Exploring Expedition. See also Lyell's Elements of Geology, 'Sandwich I. Volcanos'—Index.

The country around the Dead Sea exhibits in some spots layers of sulphur and bitumen, forming a superficial deposit, supposed by Mr. Tristram to be of volcanic origin. A district near Smyrna, in Asia Minor, was termed by the Greeks Catacecaumene, or 'the burnt up,' where there is a large arid territory, without trees, and with a cindery soil.* This country was visited in 1841 by Mr. W. J. Hamilton, who found in the valley of the Hermus perfect cones of scoriæ, with lava-streams, like those of Auvergne, conforming to the existing river-channels, and with their surface undecomposed.†

Grecian Archipelago.—Proceeding westwards, we reach the Grecian Archipelago, where Santorin, afterwards to be described, is the grand centre of volcanic action (Vol. II. Chap. XXVII.)

It was Von Buch's opinion that the volcanos of Greece were arranged in a line running N.N.W. and S.S.E., and that they afforded the only example in Europe of active volcanos having a linear direction; but M. Virlet, on the contrary, announces as the result of his investigations, made during the French expedition to the Morea in 1829, that there is no one determinate line of direction for the volcanic phenomena in Greece, whether we follow the points of eruptions, or the earthquakes, or any other signs of igneous agency.‡

Macedonia, Thrace, and Epirus have always been subject to earthquakes, and the Ionian Isles are continually convulsed.

Respecting Southern Italy, Sicily, and the Lipari Isles, it is unnecessary to enlarge here, as I shall have occasion again to allude to them. I may mention, however, that a band of volcanic action has been traced by Dr. Daubeny across the Italian Peninsula, from Ischia to Mount Vultur, in Apulia, the commencement of the line being found in the hot springs of Ischia, after which it is prolonged through Vesuvius to the Lago d'Ansanto, where gases similar to those of Vesuvius

* Strabo, ed. Fal. p. 900.

† Researches in Asia Minor, vol. ii. p. 39.

‡ Virlet, Bulletin de la Soc. Géol. de France, tom. iii. p. 109.

are evolved. Its farther extension strikes Mount Vultur, a lofty cone composed of tuff and lava, from one side of which carbonic acid and sulphuretted hydrogen are emitted.*

Traditions of deluges.—The traditions which have come down to us from remote ages of great inundations said to have happened in Greece and on the confines of the Grecian settlements, had doubtless their origin in a series of local catastrophes, caused principally by earthquakes. The frequent migrations of the earlier inhabitants, and the total want of written annals long after the settlement of each country, make it impossible for us at this distance of time to fix either the true localities or probable dates of these events. The first philosophical writers of Greece were, therefore, as much at a loss as ourselves to offer a reasonable conjecture on these points, or to decide how many catastrophes might sometimes have become confounded in one tale, or how much this tale may have been amplified, in after times, or obscured by mythological fiction. The floods of Ogyges and Deucalion are commonly said to have happened before the Trojan war; that of Ogyges more than seventeen, and that of Deucalion more than fifteen, centuries before our era. As to the Ogygian flood, it is generally described as having laid waste Attica, and was referred by some writers to a great overflowing of rivers, to which cause Aristotle also attributed the deluge of Deucalion, which, he says, affected Hellas only, or the central part of Thessaly. Others imagined the same event to have been due to an earthquake, which threw down masses of rock, and stopped up the course of the Peneus in the narrow defile between Mounts Ossa and Olympus.

As to the deluge of Samothrace, which is generally referred to a distinct date, it appears that the shores of that small island and the adjoining mainland of Asia were inundated by the sea. Diodorus Siculus says that the inhabitants had time to take refuge in the mountains, and save themselves by flight; he also relates, that long after the event the fishermen of the island drew up in their nets the capitals of columns, 'which were the remains of cities submerged

* Daubeny on Mount Vultur, Ashmolean Memoirs. Oxford, 1835.

by that terrible catastrophe.'* These statements scarcely leave any doubt that there occurred, at the period alluded to, earthquakes and inroads of the sea accompanied by a subsidence of the coast. It is not impossible that the story of the bursting of the Black Sea through the Thracian Bosphorus into the Grecian Archipelago, which accompanied, and, as some say, caused the Samothracian deluge, may have reference to a wave, or succession of waves, raised in the Euxine by the same convulsion.

We know that subterranean movements and volcanic eruptions are often attended not only by incursions of the sea, but also by violent rains, and the complete derangement of the river drainage of the inland country, and by the damming up of the outlets of lakes by landslips, or obstructions in the courses of subterranean rivers, such as abound in Thessaly and the Morea. We need not therefore be surprised at the variety of causes assigned for the traditional floods of Greece, by Herodotus, Aristotle, Diodorus, Strabo, and others. As to the area embraced, had all the Grecian deluges occurred simultaneously, instead of being spread over many centuries, and had they, instead of being extremely local, reached at once from the Euxine to the south-western limit of the Peloponnesus, and from Macedonia to Rhodes, the devastation would still have been more limited than that already alluded to, p. 581, which visited Chili in 1835, when a volcanic eruption broke out in the Andes, opposite Chiloe, and another at Juan Fernandez, distant 720 geographical miles, at the same time that several lofty cones in the Cordillera, 400 miles to the eastward of that island, threw out vapour and ignited matter. Throughout a great part of the space thus recently shaken in South America, cities were laid in ruins, or the land was permanently upheaved, or mountainous waves rolled inland from the Pacific.

Periodical alternation of earthquakes in Syria and Southern Italy.—It has been remarked by Von Hoff, that from the commencement of the thirteenth to the latter half of the seventeenth century, there was an almost entire cessation of

* Book v. ch. xlvi.—See Letter of M. Virlet, Bulletin de la Soc. Géol. de France, tom. ii. p. 341.

earthquakes in Syria and Judea; and, during this interval of quiescence, the Archipelago, together with part of the adjacent coast of Asia Minor, as also Southern Italy and Sicily, suffered greatly from earthquakes; while volcanic eruptions were unusually frequent in the same regions. A more extended comparison, also, of the history of the subterranean convulsions of these tracts seems to confirm the opinion, that a violent crisis of commotion never visits both at the same time. It is impossible for us to declare, as yet, whether this phenomenon is constant in this and other regions, because we can rarely trace back a connected series of events farther than a few centuries; but it is well known that, where numerous vents are clustered together within a small area, as in many archipelagos for instance, two of them are never in violent eruption at once. If the action of one becomes very great for a century or more, the others assume the appearance of spent volcanos. It is, therefore, not improbable that separate provinces of the same great range of volcanic fires may hold a relation to one deep-seated focus, analogous to that which the apertures of a small group bear to some more superficial rent or cavity. Thus, for example, we may conjecture that, at a comparatively small distance from the surface, Ischia and Vesuvius mutually communicate with certain fissures, and that each affords relief alternately to elastic fluids and lava there generated. So we may suppose Southern Italy and Syria to be connected, at a much greater depth, with a lower part of the very same system of fissures; in which case any obstruction occurring in one duct may have the effect of causing almost all the vapour and melted matter to be forced up the other, and if they cannot get vent, they may be the cause of violent earthquakes. Some objections advanced against this doctrine that 'volcanos act as safety-valves,' will be considered in the sequel.*

The north-eastern portion of Africa, including Egypt, which lies six or seven degrees south of the volcanic line already traced, has been almost always exempt from earthquakes; but the north-western portion, especially Fez and Morocco, which fall within the line, suffer greatly from time

* See Vol. II. Ch. XXXII., *Cause of Volcanic Eruptions.*

to time. The southern part of Spain, and also of Portugal, have generally been exposed to the same scourge simultaneously with Northern Africa. The provinces of Malaga, Murcia, and Granada, and in Portugal the country round Lisbon, are recorded at several periods to have been devastated by great earthquakes. It will be seen, from Michell's account of the great Lisbon shock in 1755, that the first movement proceeded from the bed of the ocean ten or fifteen leagues from the coast. So late as February 2, 1816, when Lisbon was vehemently shaken, two ships felt a shock in the ocean west from Lisbon; one of them at the distance of 120, and the other 262 French leagues from the coast*—a fact which is more interesting, because a line drawn through the Grecian Archipelago, the volcanic region of Southern Italy, Sicily, Southern Spain, and Portugal, will, if prolonged westward through the ocean, strike the volcanic group of the Azores, which may possibly therefore have a submarine connection with the European line.

In regard to the volcanic system of Southern Europe, it may be observed, that there is a central tract where the greatest earthquakes prevail, in which rocks are shattered, mountains rent, the surface elevated or depressed, and cities laid in ruins. On each side of this line of greatest commotion there are parallel bands of country where the shocks are less violent. At a still greater distance (as in Northern Italy, for example, extending to the foot of the Alps), there are spaces where the shocks are much rarer and more feeble, yet possibly of sufficient force to cause, by continued repetition, some appreciable alteration in the external form of the earth's crust. Beyond these limits, again, all countries are liable to slight tremors, at distant intervals of time, when some great crisis of subterranean movement agitates an adjoining volcanic region; but these may be considered as mere vibrations, propagated mechanically through the external covering of the globe, as sounds travel almost to indefinite distances through the air. Shocks of this kind have been felt in England, Scotland, Northern France, and Germany—particularly during the Lisbon earthquake. But these countries cannot,

* Verneur, Journal des Voyages, tom. iv. p. 111.—Von Hoff, vol. ii. p. 275.

on this account, be supposed to constitute parts of the southern volcanic region, any more than the Shetland and Orkney Islands can be considered as belonging to the Icelandic circle, because the sands ejected from Hecla have been wafted thither by the winds.

Besides the continuous spaces of subterranean disturbance, of which we have merely sketched the outline, there are other disconnected volcanic groups, of which several will be mentioned hereafter.

Lines of active and extinct volcanos not to be confounded.—We must always be careful to distinguish between lines of extinct and active volcanos, even where they appear to run in the same direction; for ancient and modern systems may interfere with each other. Already, indeed, we have proof that this is the case; so that it is not by geographical position, but by reference to the species of organic beings alone, whether aquatic or terrestrial, whose remains occur in beds interstratified with lavas, that we can clearly distinguish the relative age of volcanos of which no eruptions are recorded. Had Southern Italy been known to civilised nations for as short a period as America, we should have had no record of eruptions in Ischia; yet we might have assured ourselves that the lavas of that isle had flowed since the Mediterranean was inhabited by the species of testacea now living in the Neapolitan seas. With this assurance, it would not have been rash to include the numerous vents of that island in the modern volcanic group of Campania.

On similar grounds we may infer, without much hesitation, that the eruptions of Etna, and the modern earthquakes of Calabria, are a continuation of that action which, at a somewhat earlier period, produced the submarine lavas of the Val di Noto in Sicily. But, on the other hand, the lavas of the Euganean Hills and the Vicentin, although not wholly beyond the range of earthquakes in Northern Italy, must not be confounded with any existing volcanic system; for when they flowed, the seas were inhabited by animals of the Eocene period, almost all of them distinct from those now known to live, whether in the Mediterranean or other parts of the globe.

CHAPTER XXIV.

VOLCANIC DISTRICT OF NAPLES.

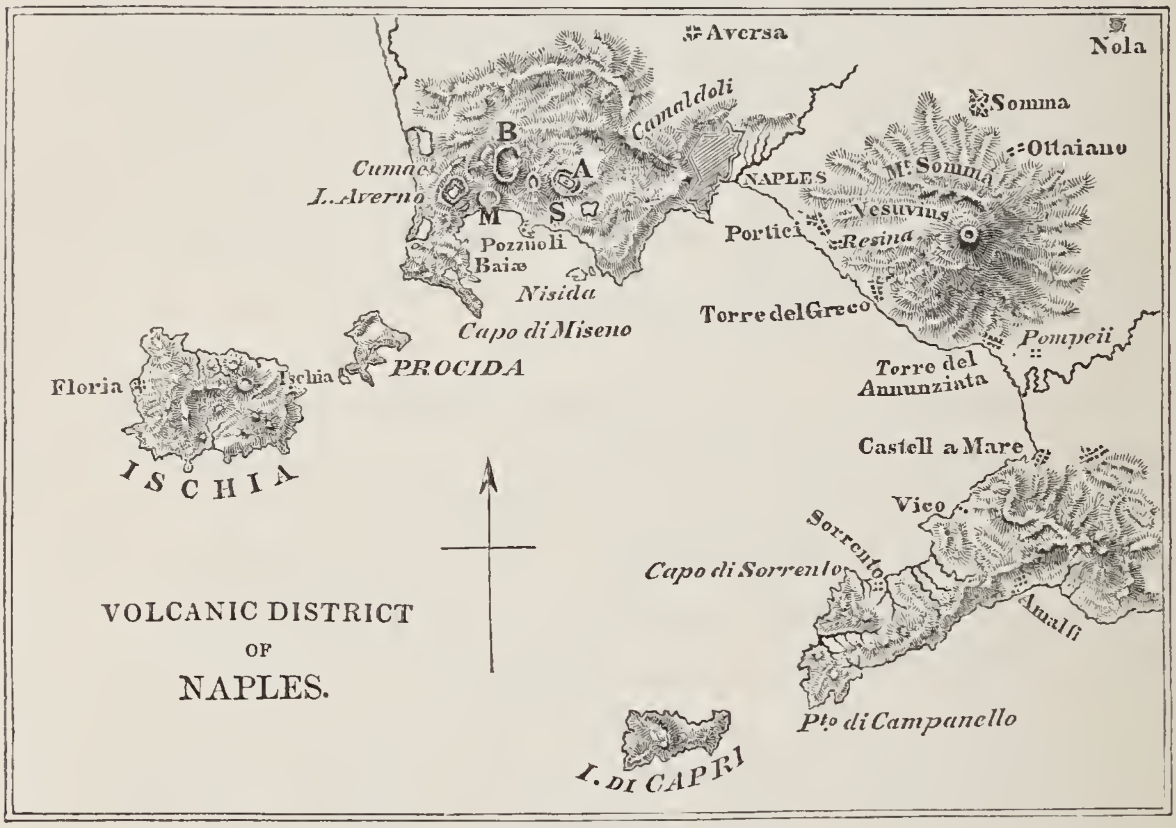
HISTORY OF THE VOLCANIC ERUPTIONS IN THE DISTRICT ROUND NAPLES—EARLY CONVULSIONS IN THE ISLAND OF ISCHIA—NUMEROUS CONES THROWN UP THERE—LAKE AVERNUS—THE SOLFATARA—RENEWAL OF THE ERUPTIONS OF VESUVIUS, A.D. 79—PLINY'S DESCRIPTION OF THE PHENOMENA—HIS SILENCE RESPECTING THE DESTRUCTION OF HERCULANEUM AND POMPEII—SUBSEQUENT HISTORY OF VESUVIUS—LAVA DISCHARGED IN ISCHIA IN 1302—PAUSE IN THE ERUPTIONS OF VESUVIUS—MONTE NUOVO THROWN UP—UNIFORMITY OF THE VOLCANIC OPERATIONS OF VESUVIUS AND PHLEGRÆAN FIELDS IN ANCIENT AND MODERN TIMES.

I SHALL next give a sketch of the history of some of the volcanic vents dispersed throughout the great regions before described, and consider the composition and arrangement of their lavas and ejected matter. The only volcanic region known to the ancients was that of the Mediterranean; and even of this they have transmitted to us very imperfect records relating to the eruptions of the three principal districts, namely, that round Naples, that of Sicily and its isles, and that of the Grecian Archipelago. By far the most connected series of records throughout a long period relates to the first of these provinces; and these cannot be too attentively considered, as much historical information is indispensable in order to enable us to obtain a clear view of the connection and alternate mode of action of the different vents in a single volcanic group.

Early convulsions in the Island of Ischia.—The Neapolitan volcanos extend from Vesuvius, through the Phlegræan Fields, to Procida and Ischia, in a somewhat linear arrangement, ranging from the north-east to the south-west, as will be seen in the annexed map of the volcanic district of Naples (fig. 66). Within the space above limited, the volcanic force

is sometimes developed in single eruptions from a considerable number of irregularly scattered points; but a great part of its action has been confined to one principal and habitual vent, Vesuvius or Somma. Before the Christian era, from the remotest periods of which we have any tradition, this principal vent was in a state of inactivity. But terrific convulsions then took place from time to time in Ischia (Pithecusa), and seem to have extended to the neighbouring isle of Procida (Prochyta); for Strabo* mentions a story of

Fig. 66.



A. Astroni. B. Monte Barbaro. M. Monte Nuovo. S. The Solfatara.

Procida having been torn asunder from Ischia; and Pliny† derives its name from its having been poured forth by an eruption from Ischia.

The present circumference of Ischia along the water's edge is eighteen miles, its length from west to east about five, and its breadth from north to south three miles. Several Greek colonies which settled there before the Christian era were compelled to abandon it in consequence of the violence of the eruptions. First the Erythræans, and afterwards the Chal-

* Lib. v. † Nat. Hist. lib. iii. c. 6.

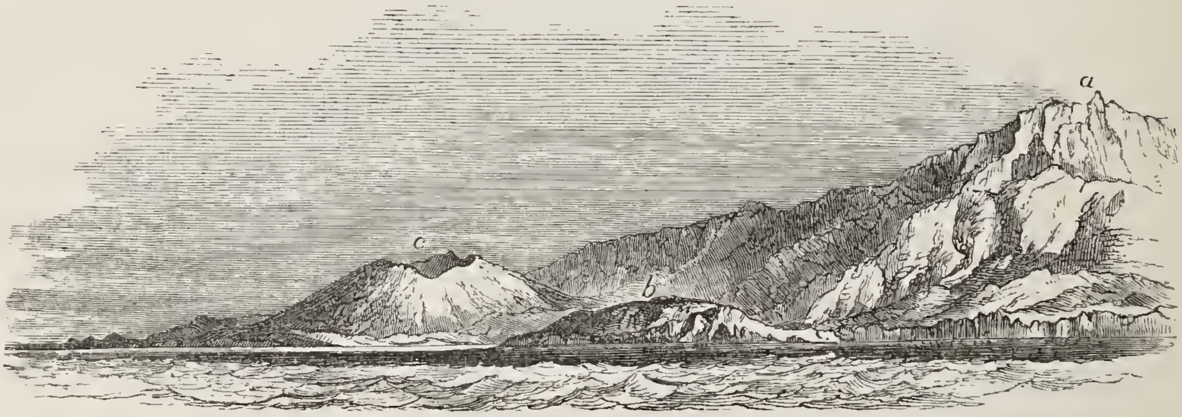
cidians, are mentioned as having been turned out by earthquakes and igneous exhalations. A colony was afterwards established by Hiero, king of Syracuse, about 380 years before the Christian era; but when they had built a fortress, they were compelled by an eruption to fly, and never again returned. Strabo tells us that Timæus recorded a tradition, that, a little before his time, Epomeus, the principal mountain in the centre of the island, vomited fire during great earthquakes; that the land between it and the coast had ejected much fiery matter, which flowed into the sea, and that the sea receded for the distance of three stadia, and then returning, overflowed the island. This eruption is supposed by some to have been that which formed the crater of Monte Corvo on one of the higher flanks of Epomeo, above Foria, the lava-current of which may still be traced, by aid of the scoriæ on its surface, from the crater to the sea.

To one of the subsequent eruptions in the lower parts of the isle, which caused the expulsion of the first Greek colony, Monte Rotaro has been attributed, and it bears every mark of recent origin. The cone, which I examined in 1828, is remarkably perfect, and has a crater on its summit precisely resembling that of Monte Nuovo near Naples; but the hill is larger, and resembles some of the more considerable cones of single eruption near Clermont in Auvergne, and, like some of them, it has given vent to a lava-stream at its base, instead of its summit. A small ravine swept out by a torrent exposes the structure of the cone, which is composed of innumerable inclined and slightly undulating layers of pumice, scoriæ, white lapilli, and enormous angular blocks of trachyte. These last have evidently been thrown out by violent explosions, like those which in 1822 launched from Vesuvius a mass of augitic lava, of many tons' weight, to the distance of three miles, which fell in the garden of Prince Ottajano. The cone of Rotaro is covered with the arbutus, and other beautiful evergreens. Such is the strength of the virgin soil, that the shrubs have become almost arborescent; and the growth of some of the smaller wild plants has been so vigorous, that botanists have scarcely been able to recognise the species.

The eruption which dislodged the Syracusan colony is supposed to have given rise to that mighty current which forms the promontory of Zaro and Caruso. The surface of these lavas is still very arid and bristling, and is covered with black scoriæ; so that it is not without great labour that human industry has redeemed some small spots, and converted them into vineyards. Upon the produce of these vineyards the population of the island is almost entirely supported. It amounted when I was first there, in 1828, to about twenty-five thousand, and was on the increase.

From the date of the great eruption last alluded to, down to our own time, Ischia has enjoyed tranquillity, with the

Fig. 67.



Part of Ischia seen from the West. From a drawing by G. P. Scrope.

a. Monte Epomeo. *b.* Monte Vico.
c. Another of the minor cones with a crater.*

exception of one emission of lava hereafter to be described, which, although it occasioned much local damage, does not appear to have devastated the whole country, in the manner of more ancient explosions. There are, upon the whole, on different parts of Epomeo, or scattered through the lower tracts of Ischia, twelve considerable volcanic cones which have been thrown up since the island was raised above the surface of the deep; and many streams of lava may have flowed, like that of 'Arso' in 1302, without cones having been produced; so that this island may, for ages before the period of the remotest traditions, have served as a safety-valve to the whole Terra di Lavoro, while the fires of Vesuvius were dormant.

* See G. Poulett Scrope, Geol. Trans. 2d series, vol. ii. pl. 34.

Lake Avernus.—It seems also clear that Avernus, a circular lake near Puzzuoli, about half a mile in diameter, which is now a salubrious and cheerful spot, once exhaled mephitic vapours, such as are often emitted by craters after eruptions. There is no reason for discrediting the account of Lucretius, that birds could not fly over it without being stifled, although they may now frequent it uninjured.* There must have been a time when this crater was in action; and for many centuries afterwards it may have deserved the appellation of 'atri janua Ditis,' emitting, perhaps, gases as destructive of animal life as those suffocating vapours given out by Lake Quilotoa, in Quito, 1797, by which whole herds of cattle on its shores were killed,† or as those deleterious emanations which annihilated all the cattle in the island of Lancerote, one of the Canaries, in 1730.‡ Bory St. Vincent mentions, that in the same isle birds fell lifeless to the ground; and Sir William Hamilton informs us that he picked up dead birds on Vesuvius during an eruption.

Solfatara.—The Solfatara, near Puzzuoli, which may be considered as a nearly extinguished crater, appears, by the accounts of Strabo and others, to have been before the Christian era in very much the same state as at present, giving vent continually to aqueous vapour, together with sulphureous and muriatic acid gases, like those evolved by Vesuvius.

Ancient history of Vesuvius.—Such, then, were the points where the subterranean fires obtained vent, from the earliest period to which tradition reaches back, down to the first century of the Christian era; but we then arrive at a crisis in the volcanic action of this district—one of the most interesting events witnessed by man during the brief period throughout which he has observed the physical changes on the earth's surface. From the first colonisation of Southern Italy by the Greeks, Vesuvius afforded no other indications of its volcanic character than such as the naturalist might infer, from the analogy of its structure to other volcanos. These were recog-

* De Rerum Nat. vi. 740.—Forbes, on Bay of Naples, Edin. Journ. of Sci., No. iii. new series, p. 87. Jan. 1830.

† Humboldt, Voy., p. 317.

‡ Von Buch, Ueber einen vulcanischen Ausbruch auf der Insel Lanzerote.

nised by Strabo, but Pliny did not include this mountain in his list of active vents. The ancient cone was of a very regular form, terminating not as at present, in two peaks, but with a summit which presented, when seen from a distance, the ordinary outline of an abruptly truncated cone. On the summit, as we learn from Plutarch, there was a crater with steep cliffs, and having its interior overgrown with wild vines, and with a sterile plain at the bottom. On the exterior, the flanks of the mountains were clothed with fertile fields richly cultivated, and at its base were the populous cities of Herculaneum and Pompeii. But the scene of repose was at length doomed to cease, and the volcanic fire was recalled to the main channel, which at some former unknown period had given passage to repeated streams of melted lava, sand, and scoriæ.

Renewal of its eruptions.—The first symptom of the revival of the energies of this volcano was the occurrence of an earthquake in the year 63 after Christ, which did considerable injury to the cities in its vicinity. From that time to the year 79 slight shocks were frequent; and in the month of August of that year they became more numerous and violent, till they ended at length in an eruption. The elder Pliny, who commanded the Roman fleet, was then stationed at Misenum; and in his anxiety to obtain a near view of the phenomena, he lost his life, being suffocated by sulphureous vapours. His nephew, the younger Pliny, remained at Misenum, and has given us, in his Letters, a lively description of the awful scene. A dense column of vapour was first seen rising vertically from Vesuvius, and then spreading itself out laterally, so that its upper portion resembled the head, and its lower the trunk of the pine, which characterises the Italian landscape. This black cloud was pierced occasionally by flashes of fire as vivid as lightning, succeeded by darkness more profound than night. Ashes fell even upon the ships at Misenum, and caused a shoal in one part of the sea—the ground rocked, and the sea receded from the shores, so that many marine animals were seen on the dry sand. The appearances above described agree perfectly with those

witnessed in more recent eruptions, especially those of Monte Nuovo in 1538, and of Vesuvius in 1822.

The younger Pliny, although giving a circumstantial detail of so many physical facts, and describing the eruption and earthquake, and the shower of ashes which fell at Stabiæ, makes no allusion to the sudden overwhelming of two large and populous cities, Herculaneum and Pompeii. In explanation of this omission, it has been suggested that his chief object was simply to give Tacitus a full account of the particulars of his uncle's death. It is worthy, however, of remark, that had the buried cities never been discovered, the accounts transmitted to us of their tragical end might well have been discredited by the majority, so vague and general are the narratives, or so long subsequent to the event. Tacitus, the friend and contemporary of Pliny, when adverting in general terms to the convulsions, says merely that 'cities were consumed or buried.' *

Suetonius, although he alludes to the eruption incidentally, is silent as to the cities. They are mentioned by Martial, in an epigram, as immersed in cinders; but the first historian who alludes to them by name is Dion Cassius,† who flourished about a century and a half after Pliny. He appears to have derived his information from the traditions of the inhabitants, and to have recorded, without discrimination, all the facts and fables which he could collect. He tells us, 'that during the eruption a multitude of men of superhuman stature, resembling giants, appeared, sometimes on the mountain, and sometimes in the environs—that stones and smoke were thrown out, the sun was hidden, and then the giants seemed to rise again, while the sounds of trumpets were heard, &c. &c.; and finally,' he relates, 'two entire cities, Herculaneum and Pompeii, were buried under showers of ashes, while all the people were sitting in the theatre.' That many of these circumstances were invented, would have been obvious, even without the aid of Pliny's letters; and the examination of Herculaneum and Pompeii enables us to prove that none of the people were destroyed in the theatres, and indeed, that there were very few of the inhabitants who

* 'Haustæ aut obrutæ urbes.'—Hist. lib. i.

† Hist. Rom. lib. lxvi.

did not escape from both cities. Yet some lives were lost, and there was ample foundation for the tale in its most essential particulars.

It does not appear that in the year 79 any lava flowed from Vesuvius; the ejected substances, perhaps, consisted entirely of lapilli, sand, and fragments of older lava, as when Monte Nuovo was thrown up in 1538. The first era at which we have authentic accounts of the flowing of a stream of lava is the year 1036, which is the seventh eruption from the revival of the fires of the volcano. A few years afterwards, in 1049, another eruption is mentioned, and another in 1138 (or 1139), after which a great pause ensued of 168 years. During this long interval of repose, two minor vents opened at distant points. First, it is on tradition that an eruption took place from the Solfatara in the year 1198, during the reign of Frederick II., Emperor of Germany; and although no circumstantial detail of the event has reached us from those dark ages, we may receive the fact without hesitation.* Nothing more, however, can be attributed to this eruption, as Mr. Scrope observes, than the discharge of a light and scoriform trachytic lava (that of Monte Olivano), of recent aspect, resting upon the strata of loose tuff which cover the principal mass of trachyte.†

Volcanic eruption in Ischia, 1302.—The other occurrence is well authenticated,—the eruption, in the year 1302, of a lava-stream from a new vent on the south-east end of the Island of Ischia. During part of 1301, earthquakes had succeeded one another with fearful rapidity; and they terminated at last with the discharge of a lava-stream from a point named the Campo del Arso, not far from the town of Ischia. The lava ran quite down to the sea—a distance of about two miles: in colour it varies from iron grey to reddish black, and is remarkable for the glassy felspar which it contains. Its surface is almost as sterile, after a period of five centuries, as if it had cooled down yesterday. A few scantlings of wild thyme, and two or three other dwarfish

* The earliest authority, says Mr. Forbes, given for this fact, appears to be Capaccio, quoted in the Terra Tremante of Bonito.—Edin. Journ. of Sci. &c., No. i., new series, p. 127. July, 1829.

† Geol. Trans., second series, vol. ii. p. 346.

plants alone appear in the interstices of the scoriæ, while the Vesuvian lava of 1767 is already covered with a luxuriant vegetation. Pontanus, whose country-house was burnt and overwhelmed, describes the dreadful scene as having lasted two months.* Many houses were swallowed up, and a partial emigration of the inhabitants followed. This eruption produced no cone, but only a slight depression, hardly deserving the name of a crater, where heaps of black and red scoriæ lie scattered around. Until this eruption, Ischia is generally believed to have enjoyed an interval of rest for about seventeen centuries; but Julius Obsequens,† who flourished A.D. 214, refers to some volcanic convulsions in the year 662 after the building of Rome (91 B.C.) As Pliny, who lived a century before Obsequens, does not enumerate this among other volcanic eruptions, the story has been thought erroneous, and it may perhaps relate to some subterranean commotions of no great violence.

History of Vesuvius after 1138.—To return to Vesuvius:—the next eruption occurred in 1306; between which era and 1631 there was only one other (in 1500), and that a slight one. It has been remarked, that throughout this period Etna was in a state of such unusual activity as to lend countenance to the idea that the great Sicilian volcano may sometimes serve as a channel of discharge to elastic fluids and lava that would otherwise rise to the vents in Campania. But we have not sufficient data as yet to enable us to form an opinion whether such a coincidence may not have been accidental and exceptional. When volcanic vents are distinctly arranged in a linear series, the subterranean connection of different portions of the line may be speculated upon more freely.

Formation of Monte Nuovo, 1538.—The great pause was also marked by a memorable event in the Phlegræan Fields—the sudden formation of a new mountain in 1538, of which we have received authentic accounts from contemporary writers.

The height of this mountain, called ever since Monte

* Lib. vi. de Bello Neap. in Grævii Thesaur.
† Prodig. libel. c. cxiv.

Nuovo, has been determined, by the Italian mineralogist Pini, to be 440 English feet above the level of the bay; its base is about 8,000 feet, or more than a mile and a half in circumference. According to Pini, the depth of the crater is 421 English feet from the summit of the hill, so that its bottom is only nineteen feet above the level of the sea. The cone is declared, by the best authorities, to stand partly on the site of the Lucrine Lake (4, fig. 69), which was nothing more than the crater of a pre-existent volcano,

Fig. 68.

Monte Nuovo, formed in the Bay of Baiæ, Sept. 29th, 1538.

1. Cone of Monte Nuovo. 2. Brim of crater of ditto.
3. Thermal spring, called Baths of Nero, or Stufe di Tritoli.

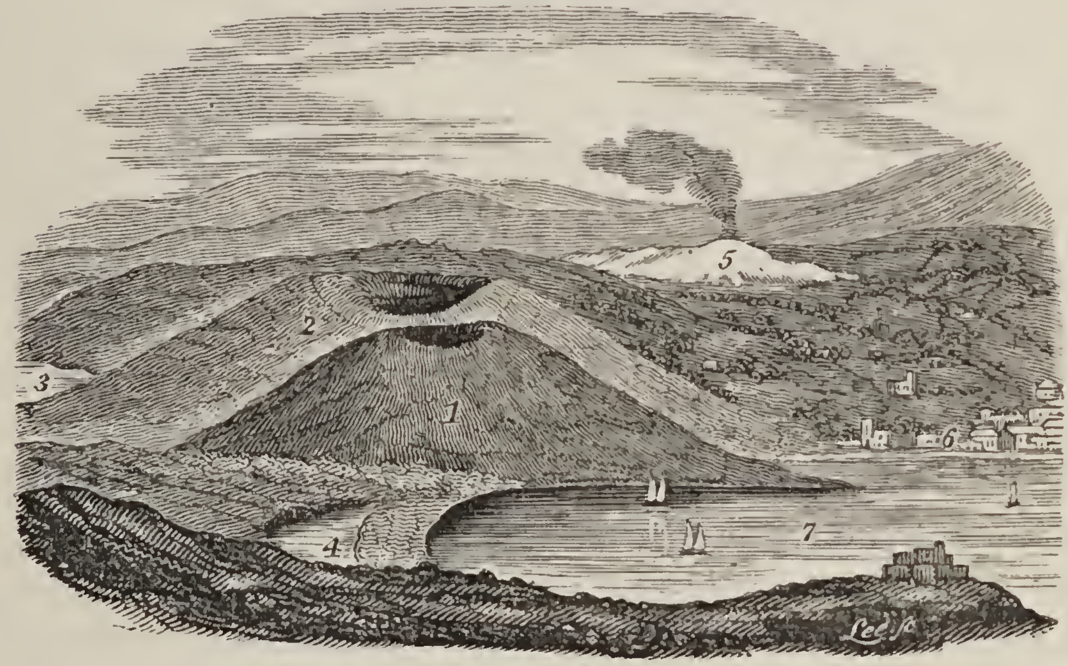
and was almost entirely filled during the explosion of 1538. Nothing now remains but a shallow pool, separated from the sea by an elevated beach, raised artificially.

Sir William Hamilton has given us two original letters describing this eruption. The first, by Falconi, dated 1538, contains the following passages.* 'It is now two years since there have been frequent earthquakes at Puzzuoli, Naples, and the neighbouring parts. On the day and in the night before the eruption (of Monte Nuovo), about twenty shocks, great and small, were felt. The eruption began on the 29th

* Campi Phlegræi, p. 70.

of September, 1538. It was on a Sunday, about one o'clock in the night, when flames of fire were seen between the hot baths and Tripergola. In a short time the fire increased to such a degree, that it burst open the earth in this place, and threw up so great a quantity of ashes and pumice-stones, mixed with water, as covered the whole country. The next morning (after the formation of Monte Nuovo) the poor inhabitants of Puzzuoli quitted their habitations in terror, covered with the muddy and black shower, which continued the whole day in that country—flying from death, but with

Fig. 69.



The Phlegræan Fields.*

1. Monte Nuovo.
2. Monte Barbaro.
3. Lake Avernus.
4. Lucrine Lake.
5. The Solfatara.
6. Puzzuoli.
7. Bay of Baiæ.

death painted in their countenances. Some with their children in their arms, some with sacks full of their goods; others leading an ass, loaded with their frightened family, towards Naples; others carrying quantities of birds, of various sorts, that had fallen dead at the beginning of the eruption; others, again, with fish which they had found, and which were to be met with in plenty on the shore, the sea having left

* These representations of the Phlegræan Fields, figs. 68 and 69, are reduced from views given by Sir William Hamilton in his great work 'Campi Phlegræi.' The faithfulness of his coloured delineations of the scenery of that country cannot be too highly praised.

them dry for a considerable time. I accompanied Signor Moramaldo to behold the wonderful effects of the eruption. The sea had retired on the side of Baiæ, abandoning a considerable tract, and the shore appeared almost entirely dry, from the quantity of ashes and broken pumice-stones thrown up by the eruption. I saw two springs in the newly-discovered ruins; one before the house that was the Queen's, of hot and salt water,' &c.

So far Falconi: the other account is by Pietro Giacomo di Toledo, which begins thus:—'It is now two years since this province of Campagna has been afflicted with earthquakes, the country about Puzzuoli much more so than any other parts: but on the 27th and the 28th of the month of September last, the earthquakes did not cease, day or night, in the town of Puzzuoli: that plain which lies between Lake Avernus, the Monte Barbaro, and the sea, was *raised a little,* and many cracks were made in it, from some of which issued water; at the same time the sea, immediately adjoining the plain, *dried up about two hundred paces,* so that the fish were left on the sand a prey to the inhabitants of Puzzuoli. At last on the 29th of the same month, about two o'clock in the night, the earth opened near the lake, and discovered a horrid mouth, from which were vomited furiously smoke, fire, stones, and mud, composed of ashes, making at the time of its opening a noise like the loudest thunder. The stones which followed were by the flames converted to pumice, and some of these were *larger than an ox.* The stones went about as high as a cross-bow can carry, and then fell down, sometimes on the edge, and sometimes into the mouth itself. The mud was of the colour of ashes, and at first very liquid, then by degrees less so, and in such quantities, that in less than twelve hours, with the help of the above-mentioned stones, a mountain was raised of 1,000 paces in height. Not only Puzzuoli and the neighbouring country was full of this mud, but the city of Naples also; so that many of its palaces were defaced by it. Now this eruption lasted two nights and two days without intermission, though, it is true, not always with the same force; the third day the eruption ceased, and I went up with many people to the top of the new hill, and saw

down into its mouth, which was a round cavity about a quarter of a mile in circumference, in the middle of which the stones which had fallen were boiling up, just as a caldron of water boils on the fire. The fourth day it began to throw up again, and the seventh much more, but still with less violence than the first night. At this time many persons who were on the hill were knocked down by the stones and killed, or smothered with the smoke. In the day the smoke still continues, and you often see fire in the midst of it in the night-time.'*

It will be seen that both these accounts, written immediately after the birth of Monte Nuovo, agree in stating that the sea retired; and one mentions that its bottom was upraised; but they attribute the origin of the new hill exclusively to the jets of mud, showers of scoriæ, and large fragments of rock, cast out from a central orifice, for several days and nights. Baron Von Buch, however, in his excellent work on the Canary Islands, and volcanic phenomena in general, has declared his opinion that the cone and crater of Monte Nuovo were formed, not in the manner above described, but by the upheaval of solid beds of white tuff, which were previously horizontal, and were pushed up in 1538, so as to dip away in all directions from the centre, with the same inclination as the sloping surface of the cone itself. 'It is an error,' he says, 'to imagine that this hill was formed by eruption, or by the ejection of pumice, scoriæ, and other incoherent matter; for the solid beds of upraised tuff are visible all round the crater, and it is merely the superficial covering of the cone which is made up of ejected scoriæ.'†

In confirmation of this view, M. Dufrénoy has cited a passage from the works of Porzio, a celebrated physician of that period, to prove that in 1538 the ground where Monte Nuovo stands was pushed up in the form of a great bubble or blister, which on bursting gave origin to the present deep crater. Porzio says, 'that after two days and nights of violent earthquakes, the sea retired for nearly 200 yards; so that the inhabitants could collect great numbers of fish on

* Campi Phlegræi, p. 77. † P. 347. Paris, 1836.

this part of the shore, and see some springs of fresh water which rose up there. At length, on the third day of the calends of October (September 29), they saw a large tract of ground intervening between the foot of Monte Barbaro and part of the sea, near the Lake Avernus, rise, and suddenly assume the form of an incipient hill; and at two o'clock at night, this heap of earth, opening as it were its mouth, vomited, with a loud noise, flames, pumice-stones, and ashes.'*

So late as the year 1846 a fourth manuscript (written immediately after the eruption) was discovered and published in Germany. It was written in 1538 by Francesco del Nero,† who mentions the drying up of the bed of the sea near Puzzuoli, which enabled the inhabitants of the town to carry off loads of fish. At about eight o'clock in the morning of the 29th September, the earth sank down about fourteen feet in that place where the volcanic orifice now appears, and there issued forth a small stream of water, at first cold, and afterwards tepid. At noon, on the same day, the earth began to swell up in the same spot where it had sunk down fourteen feet, so as to form a hill. About this time fire issued forth, and gave rise to the great gulf, 'with such a force, noise, and shining light, that I, who was standing in my garden, was seized with terror. Forty minutes afterwards, although unwell, I got upon a neighbouring height, from which I saw all that took place, and by my troth it was a splendid fire, that threw up for a long time much earth and many stones, which fell back again all round the gulf, in a semicircle of from one to three bow-shots in diameter, and, filling up part of the sea, formed a hill nearly of the height of Monte Morello. Masses of earth and stones, as large as an ox, were shot up from the fiery gulf into the air, to a height which I

* 'Magnus terræ tractus, qui inter radices montis, quem Barbarum incolæ appellant, et mare juxta Avernum jacet, sese erigere videbatur, et montis subitò nascentis figuram imitari. Eo ipso die horâ noctis II., iste terræ cumulus, aperto veluti ore, magno cum fremitu, magnos ignes evomuit; pumicesque, et lapides, cineresque.'—Porzio, Opera Omnia, Medica, Phil., et Mathemat., in unum collecta, 1736, cited by Dufrénoy, Mém. pour servir à une Description Géologique de la France, tom. iv. p. 274.

† See Neues Jahr Buch for 1846, and a translation in the Quarterly Journ. of the Geol. Soc. for 1847, vol. iii. p. 20. Memoirs.

estimate at a mile and a half. When they descended, some were dry, others in a soft muddy state.' He concludes by alluding again to the sinking of the ground, and the elevation of it which followed, and says that to him it was inconceivable how such a mass of stones and ashes could have been poured forth from the gulf. He also refers to the account which Porzio was to draw up for the Viceroy.

On comparing these four accounts, recorded by eye-witnesses, there appears to be no real discrepancy between them. It seems clear that the ground first sank down fourteen feet on the site of the future volcano, and after having subsided it was again propelled upwards by the lava mingled with steam and gases, which were about to burst forth. Jets of red-hot lava, fragments of fractured rock, and occasionally mud composed of a mixture of pumice, tuff, and sea-water, were hurled into the air. Some of the blocks of stone were very large, leading us to infer that the ground which sank and rose again was much shattered and torn to pieces by the elastic vapours. The whole hill was not formed at once, but by an intermitting action extending over a week or more. It seems that the chasm opened between the Tripergola and the baths in its suburbs, and that the ejected materials fell and buried that small town. A considerable part, however, of the hill was formed in less than twenty-four hours, and in the same manner as on a smaller scale the mud cones of air volcanos are produced, with a cavity in the middle. There is no difficulty in conceiving that the pumiceous mud, if so thrown out, may have set into a kind of stone on drying, just as some cements, composed of volcanic ashes, are known to consolidate with facility.

I am informed that Baron Von Buch discovered some marine shells of existing species, such as occur fossil in the tuff of the neighbourhood, in beds exposed low down in the wall of the crater of Monte Nuovo. These may have been ejected in the mud mixed with sea-water which was cast out of the boiling gulf; or, as Signor Arcangelo Scacchi has suggested,* they may have been derived from the older tuff, which contains marine shells of recent species. The same

* Mem. Roy. Acad. Nap. 1849.

observer remarks that Porzio's account upon the whole corroborates the doctrine of the cone having been formed by eruption, in proof of which he cites the following passage:—'But what was truly astonishing, a hill of pumice-stones and ashes was heaped up round the gulf, to the height of a mile in a single night.'* Signor Scacchi also adds that the ancient temple of Apollo, now at the foot of Monte Nuovo, and the walls of which still retain their perfect perpendicularity, could not possibly have maintained that position had the cone of Monte Nuovo really been the result of upheaval.

Tripergola was much frequented as a watering-place, and contained an hospital for those who resorted there for the benefit of the thermal springs; and it appears that there were no fewer than three inns in the principal street. Had Porzio stated that any of these buildings, or the ruins of them, were seen by himself and others raised up above the plain, a short time before the first eruption, so as to stand on the summit or slope of a newly-raised hillock, we might have been compelled, by so circumstantial a narrative, to adopt M. Dufrénoy's interpretation.

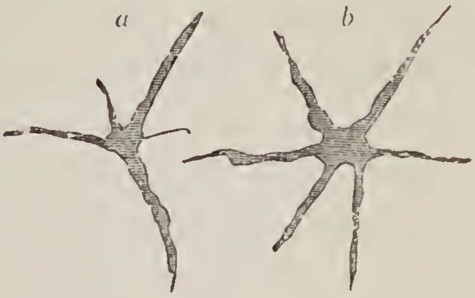
But in the absence of such evidence, we must appeal to the crater itself, where we behold a section of the whole mountain, without being able to detect any original nucleus of upheaved rock distinct from the rest: on the contrary, the whole mass is similar throughout in composition, and the cone very symmetrical in form; nor are there any clefts, such as might be looked for, as the effect of the sudden upthrow of stony masses. Mr. Constant Prévost has well remarked that if beds of solid and non-elastic materials had yielded to a violent pressure directed from below upwards, we should find not simply a deep empty cavity, but an irregular opening, where many rents converged; and these rents would be now seen breaking through the walls of the crater, widening as they approach the centre. (See fig. 70, *a*, *b*.)† Not a single fissure of this kind is observable in the interior of Monte Nuovo, where the walls of the crater are continuous and

* 'Verum quod omnem superat admirationem, mons circum eam voraginem ex pumicibus et cinere plusquam mille passuum altitudine unâ nocte congestus aspicitur.'

† Mém de la Soc. Géol. de France, tom. ii. p. 91.

entire; nor are there any dikes implying that rents had existed which were afterwards filled with lava or other matter.

Fig. 70.



It has moreover been often urged by Von Buch, De Beaumont, and others, who ascribe the conical form of volcanos chiefly to upheaval from below, that in such mountains there are a great number of deep rents and ravines, which diverge on all sides like the spokes of a wheel, from near the central axis to the circumference or base of the cone, as in the case of Palma, Cantal, and Teneriffe. Yet the entire absence of such divergent fissures or ravines, in such cases as Monte Nuovo, Somma, or Etna, is passed by unnoticed, and appears to have raised in their minds no objection to their favourite theory.

It is, indeed, admitted by M. Dufrénoy that there are some facts which it is very difficult to reconcile with his own view of Porzio's record. Thus, for example, there are certain Roman monuments at the base of Monte Nuovo, and on the borders of Lake Avernus, such as the temples of Apollo (before mentioned) and Pluto, which do not seem to have suffered in the least degree by the supposed upheaval. 'The walls which still exist have preserved their vertical position, and the vaults are in the same state as other monuments on the shores of the Bay of Baiæ. The long gallery which led to the Sibyl's Cave, on the other side of Lake Avernus, has in like manner escaped injury, the roof of the gallery remaining perfectly horizontal, the only change being that the soil of the chamber in which the Sibyl gave out her oracles is now covered by a few inches of water, which merely indicates a slight alteration in the level of Lake Avernus.'* On the supposition, then, that pre-existing beds of pumiceous tuff were upraised in 1538, so as to form Monte Nuovo, it is acknowledged that the perfectly undisturbed state of the contiguous soil on which these ancient monuments stand, is very different from what might have been expected.

* Dufrénoy, Mém. pour servir, &c., p. 277.

Mr. Darwin, in his 'Volcanic Islands,' has described several crateriform hills in the Galapagos Archipelago as composed of tuff which has evidently flowed like mud, and yet on consolidating has preserved an inclination of twenty and even thirty degrees. The tuff does not fold in continuous sheets round the hills as would have happened if they had been formed by the upheaval of horizontal layers. The author describes the composition of the tuff as very similar to that of Monte Nuovo, and the high angles at which the beds slope, both those which have flowed and those which have fallen in the form of ashes, entirely removes the difficulty supposed by M. Dufrénoy to exist in regard to the slope of Monte Nuovo, where it exceeds an angle of 18° to 20°.* Mr. Dana, also, in his account of the Sandwich Islands,† shows that in the 'cinder cones' of that region, the strata have an original inclination of between 35° and 40°, while in the 'tufa cones' formed near the sea, the beds slope at about an angle of 30°. The same naturalist also observed in the Samoan or Navigator Islands in Polynesia, that fragments of fresh coral had been thrown up together with volcanic matter to the height of 200 feet above the level of the sea in cones of tufa.‡

In October, 1857, I re-examined Monte Nuovo in company with Prof. A. Scacchi. On the south side of the mountain I saw both large and small blocks of trachyte entering into its composition, together with scoriæ, just as we might have expected from the accounts handed down to us of the eruption. In the interior of the crater on the east and north-east side an internal talus is seen, the beds of which slope at angles of 26° and 30° towards the centre or axis of the cone as at *a*, fig. 71. Such taluses are well known as characterising cones of eruption, being formed by those ejected materials which fall inside the margin of the wall of the crater, and which, although for the most part ejected again during subsequent explosions, often leave some monuments of their former existence. We found several fragments of marine

* Darwin's Volcanic Islands, p. 106, note.

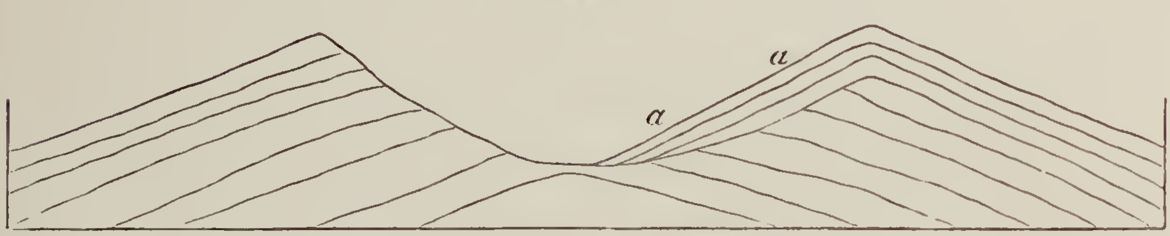
† Geology of the American Exploring Expedition, in 1838—1842, p. 354.

‡ Ibid. p. 328.

shells, *Cardium*, *Cerithium*, &c., as well as of Roman bricks, in these strata, and I myself picked up three pieces of pottery. Such remains are just what we might have looked for; they are such as would have been showered down from above on a spot where the gaseous explosions burst through marine accumulations like those of the Starza, and by which the houses of Tripergola were blown into the air.

I shall again revert to the doctrine of the origin of volcanic cones by upheaval, when speaking of Vesuvius, Etna, and Santorin, and shall now merely add, that, in 1538, the whole coast, from Monte Nuovo to beyond Puzzuoli, was upraised to the height of many feet above the bed of the Mediterranean, and has since retained the greater part of the elevation then acquired. The proofs of these remarkable changes of level will be considered at length when the phenomena of the temple of Serapis are described.*

Fig 71.



Section of Monte Nuovo showing the internal talus, *a*, *a*, on the inner slope of the crater on its north-east side.

Volcanos of the Phlegrœan Fields.—Immediately adjoining Monte Nuovo is the larger volcanic cone of Monte Barbaro (2, fig. 69, p. 609), the 'Gaurus inanis' of Juvenal—an appellation given to it probably from its deep circular crater, which is about a mile in diameter. Large as is this cone, it was probably produced by a single eruption; and it does not, perhaps, exceed in magnitude some of the largest of those formed in Ischia, within the historical era. It is composed chiefly of indurated tufa like Monte Nuovo, stratified conformably to its conical surface. This hill was once very celebrated for its wines, and is still covered with vineyards; but when the vine is not in leaf it has a sterile appearance, and, late in the year, when seen from the beautiful Bay of Baiæ,

* See Chap. XXIX.

it often contrasts so strongly in verdure with Monte Nuovo, which is always clothed with arbutus, myrtle, and other wild evergreens, that the stranger might well imagine the cone of older date to be that thrown up in the sixteenth century.*

There is nothing, indeed, so calculated to instruct the geologist as the striking manner in which the recent volcanic hills of Ischia, and that now under consideration, blend with the surrounding landscape. Nothing seems wanting or redundant; every part of the picture is in such perfect harmony with the rest, that the whole has the appearance of having been called into existence by a single effort of creative power. Yet what other result could we have anticipated if Nature has ever been governed by the same laws? Each new mountain thrown up—each new tract of land raised or depressed by earthquakes—shculd be in perfect accordance with those previously formed, if the entire configuration of the surface has been due to a long series of similar disturbances. Were it true that the greater part of the dry land originated simultaneously in its present state, at some era of paroxysmal convulsion, and that additions were afterwards made slowly and successively during a period of comparative repose; then, indeed, there might be reason to expect a strong line of demarcation between the signs of the ancient and modern changes. But the very continuity of the plan, and the perfect identity of the causes, are to many a source of deception; since by producing a unity of effect, they lead them to exaggerate the energy of the agents which operated in the earlier ages. In the absence of all historical information, they are as unable to separate the dates of the origin of different portions of our continents, as the stranger is to determine, by their physical features alone, the distinct ages of Monte Nuovo, Monte Barbaro, Astroni, and the Solfatara.

The vast scale and violence of the volcanic operations in Campania, in the olden time, has been a theme of declamation, and has been contrasted with the comparative state

* Hamilton (writing in 1770) says, 'the new mountain produces as yet but a very slender vegetation.'—Campi Phlegræi, p. 69. This remark was no longer applicable when I saw it, in 1828.

of quiescence of this delightful region in the modern era. Instead of inferring, from analogy, that the ancient Vesuvius was always at rest when the craters of the Phlegræan Fields were burning—that each cone rose in succession,—and that many years, and often centuries, of repose intervened between different eruptions,—geologists seem to have generally conjectured that the whole group sprang up from the ground at once, like the soldiers of Cadmus when he sowed the dragon's teeth. As well might they endeavour to persuade us that on these Phlegræan Fields, as the poets feigned, the giants warred with Jove, ere yet the puny race of mortals were in being.

Modern eruptions of Vesuvius.—For nearly a century after the birth of Monte Nuovo, Vesuvius continued in a state of tranquillity. There had then been no violent eruption for 492 years; and it appears that the crater was then exactly in the condition of the present extinct volcano of Astroni, near Naples. Bracini, who visited Vesuvius not long before the eruption of 1631, gives the following interesting description of the interior:—'The crater was five miles in circumference, and about a thousand paces deep: its sides were covered with brushwood, and at the bottom there was a plain on which cattle grazed. In the woody parts wild boars frequently harboured. In one part of the plain, covered with ashes, were three small pools, one filled with hot and bitter water, another salter than the sea, and a third hot, but tasteless.'* But at length these forests and grassy plains were consumed, being suddenly blown into the air, and their ashes scattered to the winds. In December, 1631, seven streams of lava poured at once from the crater, and overflowed several villages on the flanks and at the foot of the mountain. Resina, partly built over the ancient site of Herculaneum, was consumed by the fiery torrent. Great floods of mud were as destructive as the lava itself,—no uncommon occurrence during these catastrophes; for such is the violence of rains produced by the evolutions of aqueous vapour, that torrents of water descend the cone, and becoming charged

* Hamilton's Campi Phlegræi, folio, vol. i. p. 62; and Brieslak, Campanie, tome i. p. 186.

with impalpable volcanic dust, and rolling along loose ashes, acquire sufficient consistency to deserve their ordinary appellation of 'aqueous lavas.'

A brief period of repose ensued, which lasted only until the year 1666, from which time to the present there has been a constant series of eruptions, with rarely an interval of rest exceeding ten years. During these three centuries, no irregular volcanic agency has convulsed other points in this district. Brieslak remarked, that such irregular convulsions had occurred in the Bay of Naples in every second century; as, for example, the eruption of the Solfatara in the twelfth; of the lava of Arso, in Ischia, in the fourteenth; and of Monte Nuovo in the sixteenth: but the eighteenth has formed an exception to this rule, and this seems accounted for by the unprecedented number of eruptions of Vesuvius during that period; whereas, when the new vents opened, there had always been, as we have seen, a long intermittence of activity in the principal volcano.

CHAPTER XXV.

VOLCANIC DISTRICT OF NAPLES—*continued.*

DIMENSIONS AND STRUCTURE OF THE CONE OF VESUVIUS—FLUIDITY AND MOTION OF LAVA—ROPY SCORIÆ—DIKES—HYPOTHESIS OF ELEVATION CRATERS NOT APPLICABLE TO SOMMA AND VESUVIUS—SECTIONS SEEN IN VALLEYS ON THE NORTH SIDE OF MONTE SOMMA—ALLUVIUMS CALLED 'AQUEOUS LAVAS'—ORIGIN AND COMPOSITION OF THE MATTER ENVELOPING HERCULANEUM AND POMPEII—CONDITION AND CONTENTS OF THE BURIED CITIES—SMALL NUMBER OF SKELETONS—STATE OF PRESERVATION OF ANIMAL AND VEGETABLE SUBSTANCES—ROLLS OF PAPYRUS—STABIÆ—TORRE DEL GRECO—CONCLUDING REMARKS ON THE CAMPANIAN VOLCANOS.

Structure of the cone of Vesuvius.—BETWEEN the end of the eighteenth century and the year 1822, the great crater of Vesuvius had been gradually filled by lava boiling up from below, and by scoriæ falling from the explosions of minor mouths which were formed at intervals on its bottom and sides. In place of a regular cavity, therefore, there was a rough and rocky plain, covered with blocks of lava and scoriæ, and cut by numerous fissures, from which clouds of vapour were evolved. But this state of things was totally changed by the eruption of October 1822, when violent explosions, during the space of more than twenty days, broke up and threw out all this accumulated mass, so as to leave an immense gulf or chasm, of an irregular, but somewhat elliptical shape, about three miles in circumference when measured along the very sinuous and irregular line of its extreme margin, but somewhat less than three-quarters of a mile in its longest diameter, which was directed from N.E. to S.W.* The depth of this tremendous abyss has been variously estimated; for from the hour of its formation it

* Account of the Eruption of Vesuvius in October 1822, by G. P. Scrope, Esq., Journ. of Sci. &c. vol. xv. p. 175.

diminished daily by the dilapidation and falling in of its sides. It measured, at first, according to the account of some authors, 2,000 feet in depth from the extreme part of the existing summit;* but Mr. Scrope, when he saw it, soon after the eruption, estimated its depth at less than half that amount. More than 800 feet of the cone was carried away by the explosions, so that the mountain was reduced in height from about 4,200 to 3,400 feet.†

As we ascend the sloping sides, the volcano appears a mass of loose materials—a mere heap of rubbish, thrown together without the slightest order; but on arriving at the brim of the crater, and obtaining a view of the interior, we are agreeably surprised to discover that the conformation of the whole displays in every part the most perfect symmetry and arrangement. The materials are disposed in regular strata, slightly undulating, appearing, when viewed in front, to be disposed in horizontal planes. But, as we make the circuit of the edge of the crater, and observe the cliffs by which it is encircled projecting or receding in salient or retiring angles, we behold transverse sections of the currents of lava and beds of sand and scoriæ, and recognise their true dip. We then discover that they incline outwards from the axis of the cone, at angles varying from 25° to 40°. The whole cone, in fact, is composed of a number of concentric coatings of alternating lavas, sand, and scoriæ. Every shower of ashes which has fallen from above, and every stream of lava descending from the lips of the crater, have conformed to the outward surface of the hill, so that one conical envelope may be said to have been successively folded round another, until the aggregation of the whole mountain was completed. The marked separation into distinct beds results from the different colours and degrees of coarseness in the sands, scoriæ, and lava, and the alternation of these with each other. The greatest difficulty, on the first view, is to conceive how so much regularity can be produced, notwithstanding the unequal distribution of sand and scoriæ, driven by prevailing

* Mr. Forbes, Account of Mount Vesuvius, Edin. Journ. of Sci. No. xviii. p. 195. Oct. 1828.

† Ibid. p. 195.

winds in particular eruptions, and the small breadth of each sheet of lava as it first flows out from the crater.

But, on a closer examination, we find that the appearance of extreme uniformity is delusive; for when a number of beds thin out gradually, and at different points, the eye does not without difficulty recognise the termination of any one stratum, but usually supposes it continuous with some other, which at a short distance may lie precisely in the same plane. The difficulty, moreover, of following any given layer is increased by its undulating form, produced by the moulding of successive layers on the outer sides of a cone, which can never preserve perfect symmetry owing to its irregular mode of growth. As countless beds of sand and scoriæ constitute the greater part of the whole mass, these may sometimes mantle continuously round the whole cone; and even lava-streams may be of considerable breadth when first they overflow, and since, in some eruptions, a considerable part of the upper portion of the cone breaks down at once, may form a sheet extending as far as the space which the eye usually takes in, in a single section.

The high inclination of some of the beds, and the firm union of the particles even where there is evidently no cement, is another striking feature in the volcanic tuffs and breccias, which seems at first not very easy of explanation. But the great eruption of 1822 afforded ample illustration of the manner in which these strata are formed. Fragments of lava, scoriæ, pumice, and sand, when they fall at slight distances from the summit, are only half cooled down from a state of fusion, and are afterwards acted upon by the heat from within, and by fumeroles or small crevices in the cone through which hot vapours are disengaged. Thus heated, the ejected fragments cohere together strongly; and the whole mass acquires such consistency in a few days, that fragments cannot be detached without a smart blow of the hammer. At the same time sand and scoriæ, ejected to a greater distance, remain incoherent.*

Sir William Hamilton, in his description of the eruption of 1779, says that jets of liquid lava, mixed with stones and

* Monticelli and Covelli, Storia di Fenon. del Vesuv. in 1821–23.

scoriæ, were thrown up to the height of at least 10,000 feet, having the appearance of a column of fire.* Some of these were directed by the winds towards Ottajano, and some of them, falling almost perpendicularly, still red-hot and liquid, on Vesuvius, covered its whole cone, part of the mountain of Somma, and the valley (the Atrio) between them. The falling matter being nearly as vividly inflamed as that which was continually issuing fresh from the crater, formed with it one complete body of fire, which could not be less than two miles and a half in breadth, and of the extraordinary height above mentioned, casting a heat to the distance of at least six miles round it. Dr. Clarke, also, in his account of the eruption of 1793, says that millions of red-hot stones were shot into the air full half the height of the cone itself, and then bending, fell all round in a fine arch. On another occasion he says that, as they fell, they covered nearly half the cone with fire.

The same author has also described the different appearance of the lava at its source, and at some distance from it, when it had descended into the plains below. At the point where it issued, in 1793, from an arched chasm in the side of the mountain, the vivid torrent rushed with the velocity of a flood. It was in perfect fusion, unattended with any scoriæ on its surface, or any gross materials not in a state of complete solution. It flowed with the translucency of honey, 'in regular channels, cut finer than art can imitate, and glowing with all the splendour of the sun.'—'Sir William Hamilton,' he continues, 'had conceived that no stones thrown upon a current of lava would make any impression. I was soon convinced of the contrary. Light bodies, indeed, of five, ten, and fifteen pounds' weight, made little or no impression even at the source; but bodies of sixty, seventy, and eighty pounds were seen to form a kind of bed on the surface of the lava, and float away with it. A stone of 300 cwt., that had been thrown out by the crater, lay near the source of the current of lava: I raised it upon one end, and then let it fall upon the liquid lava, when it gradually sank beneath the surface, and disappeared. If I wished to describe the manner

* Campi Phlegræi.

in which it acted upon the lava, I should say that it was like a loaf of bread thrown into a bowl of very thick honey, which gradually involves itself in the heavy liquid, and then slowly sinks to the bottom.

'The lava, at a small distance from its source, acquires a darker tint upon its surface, is less easily acted upon, and, as the stream widens, the surface, having lost its state of perfect solution, grows harder and harder, and cracks into innumerable fragments of very porous matter, to which they give the name of scoriæ, and the appearance of which has led many to suppose that it proceeded thus from the mountain. There is, however, no truth in this. All lava, at its first exit from its native volcano, flows out in a liquid state, and all equally in fusion. The appearance of the scoriæ is to be attributed only to the action of the external air, and not to any difference in the materials which compose it, since any lava whatever, separated from its channel, and exposed to the action of the external air, immediately cracks, becomes porous, and alters its form. As we proceeded downward, this became more and more evident; and the same lava which, at its original source, flowed in perfect solution, undivided, and free from incumbrances of any kind, a little farther down had its surface loaded with the scoriæ in such a manner, that, upon its arrival at the bottom of the mountain, the whole current resembled nothing so much as a heap of unconnected cinders from an iron-foundry.' In another place he says, that 'the rivers of lava in the plain resembled a vast heap of cinders, or the scoriæ of an iron-foundry, rolling slowly along, and falling with a rattling noise over one another.'* Von Buch, who was in company with MM. de Humboldt and Gay-Lussac, describes the lava of 1805 (the most fluid on record) as shooting suddenly before their eyes from top to bottom of the cone in one single instant. Professor J. D. Forbes remarks that the length of the slope of the cone proper being about 1,300 feet, this motion must correspond to a velocity of many hundred feet in a few seconds, without interpreting Von Buch's expression literally. The same lava, when it reached the level road at Torre del

* Otter's Life of Dr. Clarke.

Greco, moved at the rate of only eighteen inches per minute, or three-tenths of an inch per second.* 'Although common lava,' observes Professor Forbes, 'is nearly as liquid as melted iron when it issues from the orifice of the crater, its fluidity rapidly diminishes, and as it becomes more and more burdened by the consolidated slag through which it has to force its way, its velocity of motion diminishes in an almost inconceivable degree; and at length, when it ceases to present the slightest external trace of fluidity, its movement can only be ascertained by careful and repeated observations, just as in the case of a glacier.'†

It appears that the intensity of the light and heat of the lava varies considerably at different periods of the same eruption, as in that of Vesuvius in 1819 and 1820, when Sir H. Davy remarked different degrees of vividness in the white heat at the point where the lava originated.‡

When the expressions 'flame' and 'smoke' are used in describing volcanic appearances, they must generally be understood in a figurative sense. We are informed, indeed, by M. Abich, that he distinctly saw, in the eruption of Vesuvius in 1834, the flame of burning hydrogen; § but what is usually mistaken for flame consists of vapour or scoriæ, and impalpable dust illuminated by that vivid light which is emitted from the crater below, where the lava is said to glow with the splendour of the sun. The clouds of apparent smoke are formed either of aqueous and other vapour, or of finely comminuted scoriæ.

Ropy scoriæ.—In their descriptions of lava, geologists often speak of 'ropy scoriæ,' for sometimes a large portion of the scoriform surface assumes the appearance of coils of cable. This structure I saw very conspicuously displayed by the lava of 1857, where it had poured over from the lip of the crater and descended the N.N.E. side of the cone. There were no loose fragments of scoriæ upon it, and the surface had the form partly of ropes and partly of the roots of trees. Occasionally we may observe such lavas on Etna

* Phil. Trans. 1846, p. 154.

† Ibid. p. 148.

‡ Ibid. p. 241.

§ Bulletin de la Soc. Géol de France, tom. vii. p. 43; and Illustration of Vesuvius and Etna, p. 3.

and Vesuvius, especially near the points from which they issued, exhibiting, for a short distance, flattened spaces a few feet or yards wide, on which the rope-like coils are arranged one within another, all bending the same way, as *a b c* in fig. 72. I had an opportunity in 1858 of seeing the manner

Fig. 72.

in which this structure originates. The highest crater of Vesuvius was then tranquil or only emitting steam; but half way down the mountain on the side towards Naples and below the Piano di Ginestra, were two cones which had recently been thrown up. Near the base of one of these was a grotto, from which lava had been flowing without intermission for several months, and was still pouring out in a perfectly liquid state. It had built up a ridge between 10 and 15 feet in height, at the top of which it had formed a straight canal 5 feet wide. At the point where it issued from the grotto, it seemed as fluid as water, and was at a white heat. In order to enable me to approach near enough to watch its movements without being scorched, my guides held up between me and the fiery stream a bull's-hide screen pierced with small holes, through which we looked.

At the distance of about two yards from the grotto, the lava flowing with great velocity in the canal, began to turn from white to red, and a few feet farther on it acquired a darker colour, and many small separate pieces of scoriæ were seen floating on its surface, showing that solidification had commenced. About four yards from the point of efflux, the surface of the stream had already become black, and the detached pieces of scoriæ had begun to be pressed against each other so as to unite, and they soon became welded together into continuous ropy coils, each set bending forward in the middle where the stream ran fastest, and fitting one within the other, as in fig. 72. Their successive formation and

arrangement reminded me of the manner in which wreaths of foam collect on a river below a cataract or the piers of a bridge, and being carried by a current or by the wind against a bank or island, retain for some time the marks of having been formed on the surface one after the other. The course of a lava-stream may always be known by the direction in which such coils are bent.

Dikes in the recent cone, how formed.—The inclined strata before mentioned which dip outwards in all directions from the axis of the cone of Vesuvius, are intersected by veins or dikes of compact lava, for the most part in a vertical position. In 1828 these were seen to be about seven in number, some of them not less than 400 or 500 feet in height, and thinning out before they reached the uppermost part of the cone. Being harder than the beds through which they pass, they have decomposed less rapidly, and therefore stand out in relief. When I visited Vesuvius, in November 1828, I was prevented from descending into the crater by the constant ejections then thrown out; so that I got sight of three only of the dikes; but Signor Monticelli had previously had drawings made of the whole, which he showed me. The dikes which I saw were on that side of the cone which is encircled by Somma. The eruption before mentioned, of 1828, began in March, and in the November following the ejected matter had filled up nearly one-third of the deep abyss formed at the close of the eruption in 1822. In November I found a single black cone at the bottom of the crater continually throwing out scoriæ, while on the exterior of the cone I observed the lava of 1822, which had flowed out six years before, not yet cool, and still evolving much heat and vapour from crevices.

Hoffmann, in 1832, saw on the north side of Vesuvius, near the peak called Palo, a great many parallel bands of lava, some from 6 to 8 feet thick, alternating with scoriæ and conglomerate. These beds, he says, were cut through by many dikes, some of them 5 feet broad. They resemble those of Somma, the stone being composed of grains of leucite and augite.*

* Geognost. Beobachtungen, &c. p. 182. Berlin, 1839.

There can be no doubt that the dikes above mentioned have been produced by the filling up of open fissures with liquid lava; but of the date of their formation we know nothing farther than that they are all subsequent to the year 79, and, relatively speaking, that they are more modern than all the lavas and scoriæ which they intersect. A considerable number of the upper strata are not traversed by them. That the earthquakes, which almost invariably precede eruptions, occasion rents in the mass, is well known; and, in 1822, three months before the lava flowed out, open fissures, evolving hot vapours, were numerous. It is clear that such rents must be injected with melted matter when the column of lava rises, so that the origin of the dikes is easily explained, as also the great solidity and crystalline nature of the rock composing them, which has been formed by lava cooling slowly under great pressure.

Scacchi, in his detailed narrative of what happened from day to day in the eruption of 1850, gives an account of a long linear opening or fracture on the N.N.E. side of the cone of Vesuvius, from one part of which lava issued. This chasm marked, no doubt, the site of what has now become a dike traversing the mountain. When Signor Scacchi accompanied me to the Atrio, in 1858, the chasm alluded to was still visible on the slope of the cone, though even then it had been partly filled by the lava of 1857, which descending from the lip of the crater had flowed into it.

It has been suggested that the frequent rending of volcanic cones during eruptions may be connected with the gradual and successive upheaval of the whole mass in such a manner as to increase the inclination of the beds composing the cone; and in accordance with the hypothesis before proposed for the origin of Monte Nuovo, Von Buch supposes that the present cone of Vesuvius was formed in the year 79, not by eruption, but by upheaval; and that it was not produced by the repeated superposition of scoriæ and lava cast out or flowing from a central source, but by the uplifting of strata previously horizontal. The entire cone, according to his view, rose at once, such as we now see it, from the interior and middle of Somma, and has since received no accession of

height, but, on the contrary, has ever since been diminishing in elevation.*

I shall endeavour to show that this hypothesis of Von Buch, whether applied to the modern cone of Vesuvius or to the more ancient cone called Somma, is wholly untenable. But before enlarging on this topic, I may mention some facts recorded by M. Abich in his account of the Vesuvian eruptions of 1833 and 1834, because they might seem at first sight to favour the possibility of such a mode of origin.† In the year 1834, the great crater of Vesuvius had been filled up nearly to the top with lava, which had consolidated and formed a level and unbroken plain, except that one small cone of scoriæ had been thrown up, which rose in the middle of the plain like an island in a lake. At length this flat area of lava was broken by a fissure which passed from N.E. to S.W., and along this line a great number of minute cones emitting vapour were produced. The first act of formation of these minor cones consisted, according to Abich, of a partial upheaval of beds of lava previously horizontal, and which had been rendered flexible by the heat and tension of elastic fluids, which, rising from below, escaped from the centre of each new monticule. There would be considerable analogy between this mode of origin and that ascribed by Von Buch to Vesuvius and Somma, if the dimensions of the upraised masses were not on so different a scale, and if it was safe to reason from the inflation of bladders of half-used lava, from 15 to 25 feet in height, to mountains attaining an altitude of several thousand feet, and having their component strata strengthened by intersecting dikes of solid lava.

At the same time M. Abich mentions, that when, in August 1834, a great subsidence took place in the platform of lava within the great crater, so that the structure of the central cone was laid open, it was seen to have been evidently formed, *not by upheaval*, but by the fall of cinders and scoriæ which had been thrown out during successive eruptions.‡

Mr. Scrope, writing in 1827, attributed the formation of a

* Von Buch, Descrip. Phys. des Iles Canaries, p. 342. Paris, 1836.

† Abich, Vues Illust. de Phénom. Géol. sur le Vésuve et l'Etna. Berlin, 1837.

‡ Ibid. p. 2.

volcanic cone chiefly to matter ejected from a central orifice, but partly to the injection of lava into dikes, and 'to that force of gaseous expansion, the intensity of which, in the central parts of the cone, is attested by local earthquakes, which so often accompany eruptions.'* The inclination of some of the lavas may, no doubt, have been modified in some cases during the rending and dislocation of the cone, but I do not believe, any more than does the author just cited, that such disturbances have played a conspicuous part in giving to volcanic mountains the configuration, whether external or internal, by which they are distinguished.

Previous to the year 79 of our era, Vesuvius appears, from the description of its figure given by Strabo, to have been a truncated cone, having a level and even outline as seen from a distance. That it had a crater on its summit, we may infer from a passage in Plutarch, on which Dr. Daubeny has judiciously commented in his treatise on volcanos.† The walls of the crater were evidently entire, except on one side, where there was a single narrow breach. When Spartacus, in the year 72 B.C., encamped his gladiators in this hollow, Clodius, the prætor, besieged him there, keeping the single outlet carefully guarded, and then let down his soldiers by scaling ladders over the steep precipices which surrounded the crater, at the bottom of which the insurgents were encamped. On the side towards the sea, the walls of this original cavity, which must have been three miles in diameter, have been destroyed, and Brieslak was the first to announce the opinion that this destruction happened during the tremendous eruption which occurred in A.D. 79, when the new cone, now called Vesuvius, was thrown up, which stands encircled on three sides by the ruins of the ancient cone, called Monte Somma.

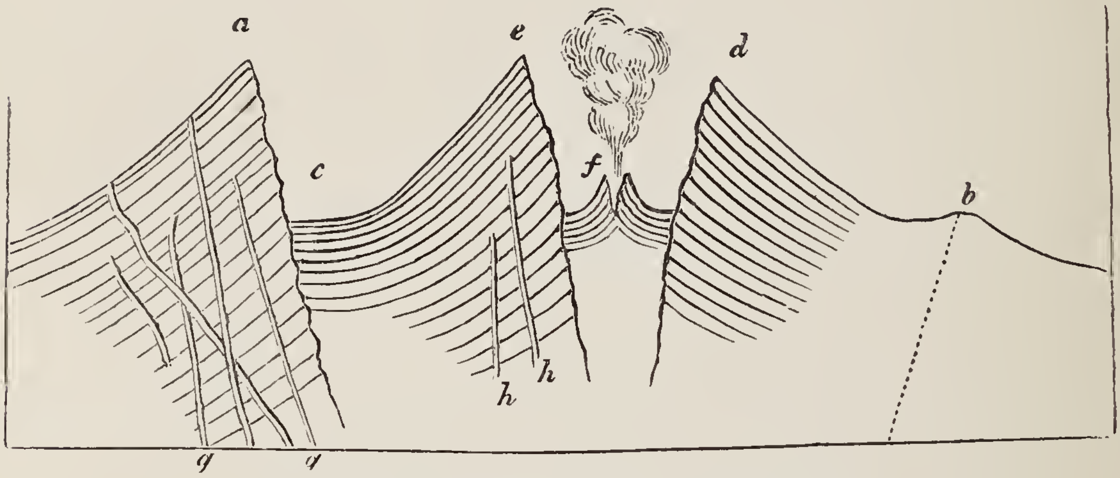
In the annexed diagram (fig. 73) it will be seen that on the side of Vesuvius opposite to that where a portion of the ancient cone of Somma (*a*) still remains, is a projection (*b*) called the Pedamentina, which some have supposed to be part of the circumference of the ancient crater broken down towards the sea, and over the edge of which the lavas of the

* Geol. Trans. 2nd series, vol. ii. p. 341.
† 2nd edit. 1848, p. 216.

modern Vesuvius have poured; the axis of the present cone of Vesuvius being, according to Visconti, precisely equidistant from the escarpment of Somma and the Pedamentina.

In the same diagram I have represented the slanting beds of the cone of Vesuvius as becoming horizontal in the Atrio del Cavallo at (*c*), where the base of the new cone meets the precipitous escarpment of Somma; for when the lava flows down to this point, as happened in 1822, its descending course is arrested, and it then runs in another direction along this

Fig. 73.



Supposed section of Vesuvius and Somma.

a. Monte Somma, or the remains of the ancient cone of Vesuvius.
b. The Pedamentina, a terrace-like projection, encircling the base of the recent cone of Vesuvius on the south side.
c. Atrio del Cavallo.*
d, *e*. Crater left by eruption of 1822.
f. Small cone thrown up in 1828, at the bottom of the great crater.
g, *g*. Dikes intersecting Somma.
h, *h*. Dikes intersecting the recent cone of Vesuvius.

N.B. The inclination of the beds at *a*, *e*, *f*, *d*, is considerably exaggerated in this diagram for want of more space.

small valley, circling round the base of the cone. Sand and scoriæ, also, blown by the winds, collect at the base of the cone, and are then swept away by torrents; so that there is always here a flattish plain, as represented. In the same manner, the small interior cone (*f*) must be composed of sloping beds, terminating in a horizontal plain; for, while this monticule was gradually gaining height by successive ejections of lava and scoriæ, in 1828, it was always sur-

* So called from travellers leaving their horses and mules there when they prepare to ascend the cone on foot.

rounded by a flat pool of semi-fluid lava, into which scoriæ and sand were thrown.

In the steep semicircular escarpment of Somma, which faces the modern Vesuvius, we see a great number of sheets of lava inclined at an angle of about 26° and in some rare cases of 30° and more. They alternate with scoriæ, and are intersected by numerous dikes from two to four feet thick, which, like the sheets of lava, are composed chiefly of augite, with crystals of leucite, but the rock in the dikes is more compact, having cooled and consolidated under greater pressure. I saw one dike two feet thick composed of leucite and augite in that part of the wall of the Atrio called Canale del Inferno, which was as vesicular as ordinary lava; but this case is quite exceptional. Some of the dikes cut through and shift others, so that they have evidently been formed during successive eruptions.

Vesuvian minerals.—A great variety of minerals are found in the lavas of Vesuvius and Somma; augite, leucite (called by the French amphigène), felspar, mica, and olivine are most abundant. It is an extraordinary fact, that, in an area of three square miles round Vesuvius, a greater number of simple minerals have been found than in any spot of the same dimensions on the surface of the globe. Häuy enumerated only 380 species of simple minerals as known to him; and no less than eighty-two had been found on Vesuvius and in the tuffs on the flanks of Somma before the end of the year 1828. Many of these are peculiar to that locality. Some mineralogists have conjectured that the greater part of these were not of Vesuvian origin, but thrown up in fragments from some older formation, through which the gaseous explosions burst. But none of the older rocks in Italy, or elsewhere, contain such an assemblage of mineral products; and the hypothesis seems to have been prompted by a disinclination to admit that, in times so recent in the earth's history, the laboratory of Nature could have been so prolific in the creation of new and rare compounds. Had Vesuvius been a volcano of high antiquity, formed when nature

> Wanton'd as in her prime, and played at will
> Her virgin fancies,

it would have been readily admitted that these, or a much greater variety of substances, had been sublimed in the crevices of lava, just as several new earthy and metallic compounds are known to have been produced by fumeroles, since the eruption of 1822.

At the fortress near Torre del Greco a section is exposed, fifteen feet in height, of a current which ran into the sea; and it evinces, especially in the lower part, a decided tendency to divide into rude columns.

Mr. Scrope mentions that, in the cliffs encircling the modern crater of Vesuvius, he saw many currents offering a columnar division, and some almost as regularly prismatic as any ranges of the older basalts; and he adds, that in some the spheroidal concretionary structure, on a large scale, was equally conspicuous. Brieslak also informs us that, in the siliceous lava of 1737, which contains augite, leucite, and crystals of felspar, he found very regular prisms in a quarry near Torre del Greco; an observation confirmed by modern authorities.

Hypothesis of elevation craters not applicable to Monte Somma or to Vesuvius.—It has been imagined by MM. Von Buch and Dufrénoy, that a large part of the tufaceous strata which rise in Somma to more than half the height of the mountain are of submarine origin, an opinion which I shall show to be quite untenable. The same writers, as well as M. E. de Beaumont, have also taught that the sheets of lava which we see in the great section of Somma laid open in the Atrio, could not originally have been inclined at angles of more than four or five degrees, so that four-fifths of their present slope must be due to their having been subsequently heaved up and tilted. Their original approach to horizontality was inferred from the compact structure of many of the beds, as well as their supposed parallelism and continuity in the line of their strike. M. E. de Beaumont, in particular, has contended that if they had run down a greater inclination than four degrees, and still more decidedly if they had poured down a slope exceeding twenty degrees, they would have consisted not of broad sheets of solid rock, but of narrow streams of porous lava and scoriæ.

I should have been at a loss to account for the support which the theoretical views above stated have received from men of such eminence, had I not been assured by my scientific friends at Naples that no one of those geologists ever visited the numerous ravines which intersect the north side of Monte Somma. In exploring these deep and narrow valleys I had the good fortune to be accompanied by Signor Guiscardi, than whom no one possesses a more thorough knowledge of the structure and composition both of Vesuvius and Monte Somma. On looking at the latter mountain from the north, I was struck with its general resemblance to old volcanic cones such as I have seen in the Canary Islands (Palma, for example), or such as Junghuhn has described in Java. From the crest of the great escarpment of the 'Atrio,' or what the Spaniards would call the 'Caldera,' deep ravines or 'barrancos,' very near each other radiate outwards in all directions, towards the north-west, north, and north-east, very shallow near the summit, but becoming rapidly deeper and having precipitous sides towards their terminations, as near the towns or villages of Santa Anastasia, Somma, and Ottajano. At the upper end of the ravine-like portion of several of these valleys is frequently seen a precipice over which a cascade falls in the rainy season when the channel of the torrent above is full of water. Passing upwards from St. Anastasia into the valley called the Casa dell' Acqua, I saw at the head of that ravine a perpendicular cliff, which is the site of one of these waterfalls, which was dry at the time. The cliff was 60 feet in height, and consisted of thin beds of stony lava interstratified with others which were more scoriaceous, and some of which were formed of loose pieces of scoriæ. At the head of an adjoining ravine called the Fosso di Cancheroni, is a much finer precipice, between 200 and 300 feet high, over which the water is thrown after heavy rains. It exhibits a great succession of beds of lava, some of them of a red colour, and much like the modern streams from Vesuvius, divided by strata of scoriæ, tuff, and breccia, the latter containing fragments of lava often leucitic, sometimes angular, and sometimes rounded by attrition. These last imply that there were gullies of aqueous erosion on the ancient flanks of Somma.

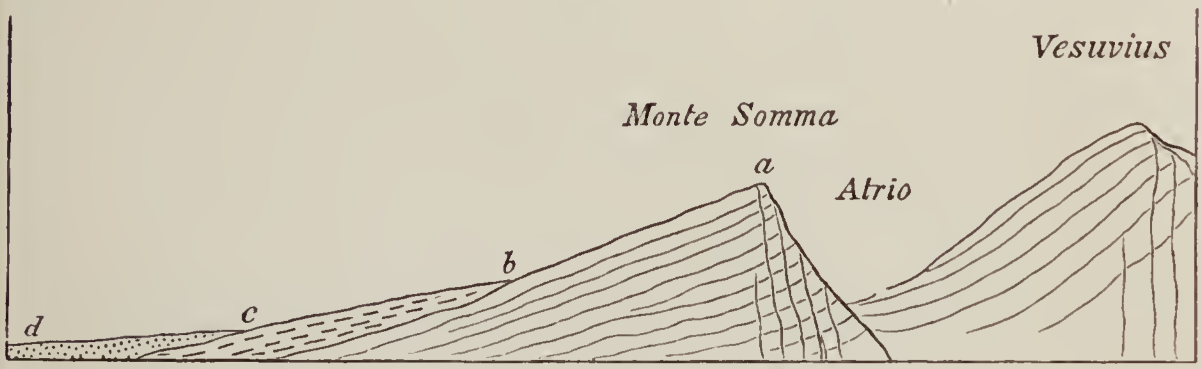
The ravine-like character of these 'barrancos' is due, I conceive, to their having been excavated by torrents cutting their way backwards. In a neighbouring valley, namely, that of Olivelli, are seen trachytic lavas with pumiceous tuffs like those which cover Pompeii, but of much older date. Blocks of white dolomite, sometimes more than a foot in diameter, occur, though rarely in the ancient tuffs, as well as blocks of lava four or five feet in diameter. Above the village of Somma we examined the parallel and adjoining ravines called the Vallone di Panico and the Vallone di Castello. Although they are very near each other, the dissimilarity of the sections which they present to the geologist is very marked. It is the same everywhere, the greatest diversity of character prevailing in the details of structure instead of that uniformity, for explaining which the theory of upheaval or elevation craters was invented. Thus, on the right side of the ravine called the Casa dell' Acqua is seen a pink lava more than 30 feet thick, containing crystals of augite and leucite, and inclined at an angle of 20 degrees, to which there is nothing answering in the next closely adjoining valleys to the east and west. The same dense mass terminates abruptly at its lower end. Some of the lavas and tuffs in the same ravine are unconformable to other sets, and must have flowed down after valleys had been excavated in the flanks of the old cone. The entire absence of dikes in most of the valleys, even in those upper parts of them which are only separated by a distance of a few hundred yards from the section in the Atrio where the dikes are so abundant, would have surprised me had I not been familiar with the same phenomenon in other volcanic mountains, especially the Canaries, where the dikes are almost entirely confined to the vicinity of the grand centres of eruption.

The annexed section (fig. 74) may give some idea of the general character of the north of Somma, so far as it is possible to represent in one view the structure of a cone, the separate parts of which are so unlike each other. The dikes so conspicuous in the Atrio terminate soon after the crest *a*; from *a* to *b* a great thickness of stony and scoriaceous lava, dipping at angles of about 20 degrees, is most conspicuous;

and from *b* to *c* white pumiceous tuffs abound, some beds having a steep, others a very slight dip, while towards the plain at *d* modern tufaceous alluvium is spread over the surface.

In no one of the tuffs in these sections have any marine shells been found; but, what is still more decisive of the sub-aerial origin of the whole mass, is the frequent occurrence of the leaves of ferns and of dicotyledonous shrubs and trees. These have been found in the valleys above St. Sebastian as well as above St. Anastasia and Ottajano—in a word, along the whole range of the flanks of the mountain, from east to west. Sometimes trunks of trees and carbonised wood occur in the tuffs at heights of 1,000 and 2,000 feet above the

Fig. 74.



Section of the north side of Monte Somma and Vesuvius.

sea, as in the valley of the Casa dell' Acqua. Leaves of the oak are not uncommon, but those of the butcher's broom, *Ruscus aculeatus*, are by far the most frequent. I believe that a rich terrestrial flora will one day be obtained from these tuffs.

Fossil sea-shells have been found in ejected fragments of sandstone and tuff in the older parts of Vesuvius on the side of Naples at the height of 972 feet above the sea; especially at a place near the Fosso Grande called the Rivo di Quaglia, which I visited with Signor Guiscardi. That gentleman has published an account of about a hundred species of marine shells, all of them save one, *Buccinum semistriatum*, of species now living in the Mediterranean, which he has obtained from fragments of tuff and sandstone cast up into the air at some

remote period and then imbedded in the old tuffs like pieces of dolomite and other rocks foreign to the mountain. They only prove that some of the early eruptions burst through tuffs of marine origin like those found between Naples and Vesuvius. Such tuffs contain similar shells, but seem only to rise to the height of about thirty feet above the level of the sea.

As to the sea-shells said to have been found on the north side of Somma, I learned that the guides, finding such fossils to be in request, have been in the habit of taking from the sea-shore fragments of tuff covered with the recent Vermetus and passing them off as fossils belonging to ancient and highly elevated beds on the flanks of Somma.

There is nothing in the dimensions of Somma which is opposed to the notion of its having originated from the same central axis of eruption as that by which the modern Vesuvius has been formed. I observed in 1857 that the top of the escarpment where it lowers towards Ottajano, as well as the flank of the old mountain below, was almost entirely devoid of vegetation, from the sterilising effect of the volcanic sand and lapilli which fell upon it during the eruption of 1822, and which were more than a foot thick at this great distance from the crater. I found in them some of those pear-shaped masses of scoriæ called volcanic bombs, also projected from the crater in 1822. This circumstance, together with the fact that the opposite side of Vesuvius was in like manner reached at an equal distance from the present centre of eruption by the matter then ejected, is a clear proof that we want no greater power than that possessed by the existing volcanos to reconstruct a cone having as large a diameter as Somma. No upheaval is wanted to perform such a feat, the ordinary forces of the elastic vapours being amply sufficient to form such a cone by ejected matter only.

The ravines then on the north side of Somma demonstrate that the origin of that mountain was due to successive flows of lava and showers of scoriæ, and that there were many long intervals of rest between successive eruptions, during which valleys of aqueous erosion were scooped out, and forest-trees and shrubs had time to grow. These plants were sometimes buried in showers of pumiceous matter, or

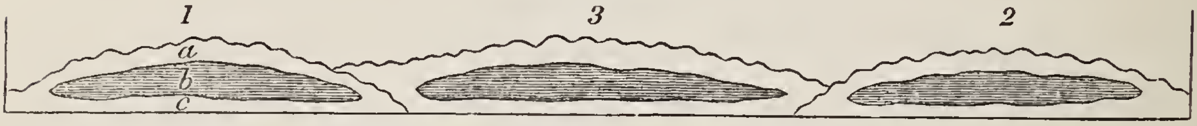
in mud sweeping down the steep slopes. But how, it will be asked, can we reconcile with all these appearances the structure of the mountain at a short distance from the ravines above described, such as is revealed to us in the grand section of the Atrio? In reply to this question, I may remark that there is no difficulty when once a close inspection is made of the arrangement and composition of those beds which are intersected by numerous dikes in the great escarpment alluded to. They are as irregular as the modern lava-streams and showers of ashes which in the years 1855 and 1857 descended slopes of between 18 and 30 degrees, and formed new envelopes of the cone arranged one above the other.

In that part of the precipice exposed in the Atrio which is called Canale del Inferno, flows of lava may be seen 12 feet thick, and consisting exclusively of fragmentary scoriæ. In many other cases the only part composed of solid rock is no more than one or two feet thick, above and below which the mass is scoriaceous and fragmentary. Not a few of these lavas may originally have formed narrow stripes on the steep slope of the ancient Somma, like those narrow bands which I saw formed by the lavas of 1855–57 and 1858, and some of which I watched descending rapidly in 1857 down the modern cone. But the enquiry will still be made, how is it possible that those continuous and horizontal sheets of stony lava, the edges of which every observer recognises in the escarpment of Somma, could have been formed by narrow rills of fluid matter descending a slope of 20 degrees? The simple answer is, that there are no such extensive stony beds. Signor Guiscardi and I convinced ourselves, in 1858, that the supposed existence of them is a delusion. There are some beds of whitish tuff, one in particular, which is very conspicuous, which the eye traces for a great length, in the middle of the great section, and which, seen at the distance, have the character of stony layers. They may have been produced simultaneously throughout their whole extent in the same manner as some layers of scoriæ of modern date, which have been seen to fall red-hot from the air, and to cover the wide expanse of the mountain-side with a mantle of fire. But when real sheets of stony lava are examined, they are never seen to reach far in a

horizontal direction, but thin out, and pass laterally into scoriæ.

I measured carefully the dimensions of one of the numerous streams of 1857, and found it to be 50 feet wide, and inclined, like the surface of the cone on which it rested, at angles varying from 18 to 28 degrees. Its average thickness was 10 feet. Having had opportunities of studying several fine cross-sections of the modern lavas of Mount Etna, which had consolidated on still steeper slopes,* I feel sure that a section of the stream in question would be such as is represented at No. 1, fig. 75, in which the central mass *b* would

Fig. 75.



Structure of successive juxtaposed modern lava-streams.

be as compact and stony as the ordinary lava of Somma, while *a* and *c* would consist of scoriaceous materials. The lower layer of scoriæ *c* is usually the least thick; it is formed in part by the sudden cooling of the lava pouring over the cold and damp soil, while the upper bed *a* is that which consolidates by contact with air. But as the mass *a b c* would rest on an old lava, the layer *c* would join on to the upper scoriæ of a subjacent stream, so that the solid and stony mass *b* would be separated by a bed of considerable thickness from the solid layer next below. The stream No. 2 next flows down and has a similar structure, and to this succeeds the third stream, No. 3, which fills up the interspace between Nos. 1 and 2, and is also made up in like manner of three parts; a cross-section of the whole exhibiting a central, almost continuous stony layer of precisely homogeneous rock, because all of the lavas proceed from one caldron of fluid matter, like those thirty or more currents which issued from the crater in 1857. Probably the beds of Monte Somma seen in the Atrio at the bottom of the great section were formed originally near the base of the cone, which had only then attained a small part of its present dimensions, and the

* See paper by the author on the Structure of Etna, Phil. Trans. 1858, p. 734.

inclination there being less than 18 degrees, some currents may have been wider than those which I saw in 1857, shooting down slopes of 30 degrees.

In the escarpment of the Atrio, the stony lavas form no more than a seventh part of the whole mass, the rest consisting of tuff or volcanic sand and fragmentary scoriæ. I observed at many points ropy lavas in this section, and some grottos which indicate tunnels like those in which modern lavas often flow (see above, p. 627). For a short distance, some stony layers in the Atrio have so steep a dip as to resemble dikes; but I doubt whether even these have been tilted, for some of the lava of 1857, on the N.N.E. side of the cone near the summit, flowed down a steep slope, reaching at one point an angle of 43 degrees. I observed that its surface was ropy and root-like, and had evidently consisted of very viscous lava. It formed what was called the 'gibbosity' of 1857, and I have no doubt that it contained within it a stony layer having a dip of at least 40 degrees. Such gibbosities are caused by the abrupt termination of viscous streams, which stop at different heights on the flanks of the cone for want of a sufficient supply of melted matter to enable them to proceed farther.

Mass enveloping Herculaneum and Pompeii.—I have spoken in the description of fig. 74 of the alluvial matter which covers the plain *c*, *d*, at the foot of the mountain. Aqueous vapours are evolved copiously from volcanic craters during eruptions, and often for a long time subsequently to the discharge of scoriæ and lava; these vapours are condensed in the cold atmosphere surrounding the high volcanic peak, and heavy rains are thus caused. The floods thus occasioned sweep along the impalpable dust and light scoriæ, till a current of mud is produced, which is called in Campania 'lava d' acqua,' and is often more dreaded than an igneous stream (lava di fuoco), from the greater velocity with which it moves. On the 27th of October, 1822, one of these alluviums descended the cone of Vesuvius, and, after overspreading much cultivated soil, flowed suddenly into the villages of St. Sebastian and Massa, where, filling the streets and interior of some of the houses, it suffocated seven persons. It will,

therefore, happen very frequently that, towards the base of a volcanic cone, alternations will be found of lava, alluvium, and showers of ashes. The great eruption, in 1822, caused a covering only a few inches thick on Pompeii. Several feet are mentioned by Prof. J. D. Forbes,* but he must have measured in spots where it had drifted. The dust and ashes were five feet thick at the top of the crater, and decreased gradually to ten inches at Torre dell' Annunziata. The size and weight of the ejected fragments diminished very regularly in the same continuous stratum, as the distance from the centre of projection was greater.

To which of these two latter divisions the mass enveloping Herculaneum and Pompeii should be referred, has been a question of the keenest controversy; but the discussion might have been shortened, if the combatants had reflected that, whether volcanic sand and ashes were conveyed to the towns by running water, or through the air, during an eruption, the interior of buildings, so long as the roofs remain entire, together with all underground vaults and cellars, could be filled only by an *alluvium*. We learn from history that a heavy shower of sand, pumice, and lapilli, sufficiently great to render Pompeii and Herculaneum uninhabitable, fell for eight successive days and nights in the year 79, accompanied by violent rains. We ought, therefore, to find a very close resemblance between the strata covering these towns and those composing the minor cones of the Phlegræan Fields, accumulated rapidly, like Monte Nuovo, during a continued shower of ejected matter; with this difference, however, that the strata incumbent on the cities would be horizontal, whereas those on the cones are highly inclined; and that large angular fragments of rock, which are thrown out near the vent, would be wanting at a distance where small lapilli only can be found. Accordingly, with these exceptions, no identity can be more perfect than the form and distribution of the matter at the base of Monte Nuovo, as laid open by the encroaching sea, and the appearance of the beds superimposed on Pompeii. That city is covered with numerous alternations of different horizontal beds of tuff and

* Ed. Journ. of Science, No. xix. p. 131. Jan. 1829.

lapilli, for the most part thin, and subdivided into very fine layers. I observed the following section near the amphitheatre, in November 1828—(descending series) :—

	Feet.	Inches.
1. Black sparkling sand from the eruption of 1822, containing minute regularly formed crystals of augite and tourmaline	0	2½
2. Vegetable mould	3	0
3. Brown incoherent tuff, full of *pisolitic globules*, divided into layers, from half an inch to three inches in thickness .	1	6
4. Small scoriæ and white lapilli	0	3
5. Brown earthy tuff, with numerous pisolitic globules .	0	9
6. Brown earthy tuff, with lapilli divided into layers . .	4	0
7. Layer of whitish lapilli	0	1
8. Grey solid tuff	0	3
9. Pumice and white lapilli	0	3
	10	3½

Many of the ashes in these beds are vitrified, and harsh to the touch. Crystals of leucite, both fresh and farinaceous, have been found intermixed.* The depth of the bed of ashes above the houses is variable, but seldom exceeds 12 or 14 feet, and it is said that the higher part of the amphitheatre always projected above the surface; though if this were the case, it seems inexplicable that the city should never have been discovered till the year 1750. It will be observed in the above section, that two of the brown, half-consolidated tuffs are filled with small pisolitic globules. This circumstance is not alluded to in the animated controversy which the Royal Academy of Naples maintained with one of their members, Signor Lippi, as to the origin of the strata incumbent on Pompeii. The mode of aggregation of these globules has been fully explained by Mr. Scrope, who saw them formed in great numbers in 1822, by rain falling during the eruption on fine volcanic sand, and sometimes also produced like hail in the air, by the mutual attraction of the minutest particles of fine damp sand. Their occurrence, therefore, agrees remarkably well with the account of heavy rain, and showers of sand and ashes, recorded in history.†

* Forbes, Ed. Journ. of Science, No. xix. p. 130.

† Scrope, Geol. Trans., second series, vol. ii. p. 346.

Lippi entitled his work, 'Fù il fuoco o l'acqua che sotterò Pompei ed Ercolano?'* and he contended that the two cities were neither destroyed in the year 79, nor by a volcanic eruption, but purely by the agency of water charged with transported matter. His letters wherein he endeavoured to dispense, as far as possible, with igneous agency, even at the foot of the volcano, were dedicated, with great propriety, to Werner, and afforded an amusing illustration of the polemic style in which geological writers of that day indulged themselves. His arguments were partly of an historical nature, derived from the silence of contemporary historians, respecting the fate of the cities, and partly drawn from physical proofs. He pointed out with great clearness the resemblance of the tufaceous matter in the vaults and cellars at Herculaneum and Pompeii to aqueous alluviums, and its distinctness from ejections which had fallen through the air. Nothing, he observes, but moist pasty matter could have received the impression of a woman's breast, which was found in a vault at Pompeii, or have given the cast of a statue discovered in the theatre at Herculaneum. It was objected to him, that the heat of the tuff in Herculaneum and Pompeii was proved by the carbonisation of the timber, corn, papyrus-rolls, and other vegetable substances there discovered: but Lippi replied with truth, that the papyri would have been burnt up, if they had come in contact with fire, and that their being only carbonised was a clear demonstration of their having been enveloped, like fossil-wood, in a sediment deposited from water. The Academicians, in their report on his pamphlet, assert, that when the amphitheatre was first cleared out, the matter was arranged on the steps in a succession of concave layers, accommodating themselves to the interior form of the building, just as snow would lie if it had fallen there. This observation is highly interesting, and points to the difference between the stratification of ashes in an open building and of mud derived from the same in the interior of edifices and cellars. Nor ought we to call the allegation in question, because it could not be substantiated at the time of the controversy after the matter had been all

* Napoli, 1816.

removed; although Lippi took advantage of this removal, and met the arguments of his antagonists by requiring them to prove the fact. No stream of lava has ever reached Pompeii since it was first built, although the foundations of the town stand upon the old leucitic lava of Somma; several streams of which, with tuff interposed, had been cut through in excavations.

Infusorial beds covering Pompeii.—A most singular and unexpected discovery was made, in 1844–45, by Professor Ehrenberg respecting the nature of many of the layers of ashes and pumice enveloping Pompeii. He ascertained that they were, in great part, of organic and fresh-water origin, consisting of the siliceous cases of microscopic infusoria. What is still more surprising, this fact proves to be by no means an isolated or solitary example of an intimate relation between organic life and the results of volcanic activity. On the Rhine, several beds of tuff and pumiceous conglomerate, resembling the mass incumbent upon Pompeii and closely connected with extinct volcanos, are now ascertained to be made up to a great extent of the siliceous cases of infusoria (or rather Diatomaceæ), invisible to the naked eye and often half fused.* No less than 94 distinct species have already been detected in one mass of this kind, more than 150 feet thick, at Hochsimmer, on the left bank of the Rhine, near the Laacher-see. Some of these Rhenish infusorial accumulations appear to have fallen in showers, others to have been poured out of lake-craters in the form of mud, as in the Brohl valley.

In Mexico, Peru, the Isle of France, and several other volcanic regions, analogous phenomena have been observed, and everywhere the species of infusoria belong to fresh-water and terrestrial genera, except in the case of the Patagonian pumiceous tuffs, specimens of which, brought home by Mr. Darwin, are found to contain the remains of marine animalcules. In various kinds of pumice ejected by volcanos, the microscope has revealed to Professor Ehrenberg the siliceous

* Not a few of the organic bodies, called by Ehrenberg 'infusoria,' such as Gaillonella and Bacillaria, once supposed to belong to the animal kingdom, are now regarded by botanists as plants, and are called Diatomaceæ and Desmidiæ.

cases of infusoria often half obliterated by the action of heat, and the fine dust thrown out into the air during eruptions is sometimes referable to these most minute organic substances brought up from considerable depths, and sometimes mingled with small particles of vegetable matter.

In what manner did the solid coverings of these most minute plants and animalcules, which can only originate and increase at the surface of the earth, sink down and penetrate into subterranean cavities, so as to be ejected from the volcanic orifices? We have of late years become familiar with the fact in the process of boring Artesian wells, that the seeds of plants, the remains of insects, and even small fish, with other organic bodies, are carried in an uninjured state by the underground circulation of waters, to the depth of many hundred feet. With still greater facility in a volcanic region we may conjecture, that water and mud full of invisible infusoria may be sucked down, from time to time, into subterranean rents and hollows in cavernous lava which has been permeated by gases, or in rocks dislocated by earthquakes. It often happens that a lake which has endured for centuries in a volcanic crater, disappears suddenly on the approach of a new eruption. Violent shocks agitate the surrounding region, and ponds, rivers, and wells are dried up. Large cavities far below may thus become filled with fen-mud chiefly composed of the more indestructible and siliceous portions of infusoria, destined perhaps to be one day ejected in a fragmentary or half-fused state, yet without the obliteration of all traces of organic structure.*

Herculaneum.—It was remarked that no lava has flowed

* See Ehrenberg, Proceedings (Berichte) of the Royal Acad. of Sci. Berlin, 1844, 1845, and an excellent abstract of his papers by Mr. Ansted in the Quart. Journ. of the Geol. Soc. London, No. 7, Aug. 1846. In regard to marine infusoria found in volcanic tuff, it is well known that on the shores of the island of Cephalonia in the Mediterranean (Proceedings, Geol. Soc. vol. ii. p. 220) there is a cavity in the rock, into which the sea has been flowing for ages, and many others doubtless exist in the leaky bottom of the ocean. The marine current has been rushing in for many years, and as the infusoria inhabiting the waters of the Mediterranean are exceedingly abundant, a vast store of their cases may accumulate in submarine caverns (the water, perhaps, being converted into steam, and so escaping upwards), and they may then be cast up again to furnish the materials of volcanic tuff, should an eruption occur like that which produced Graham Island, off the coast of Sicily, in 1831.

over the site of Pompeii, since that city was built, but with Herculaneum the case is different. Although the substance which fills the interior of the houses and the vaults in that buried city must have been introduced in a state of mud, like that found in similar situations in Pompeii, yet the superincumbent mass differs wholly in composition and thickness. Herculaneum was situated several miles nearer to the volcano, and has, therefore, been always more exposed to be covered, not only by showers of ashes, but by alluviums and streams of lava. Accordingly, masses of both have accumulated on each other above the city, to a depth of nowhere less than 70, and in many places of 112 feet.*

The tuff which envelopes the buildings consists of comminuted volcanic ashes, mixed with pumice. A mask embedded in this matrix has left a cast, the sharpness of which was compared by Hamilton to those in plaster of Paris; nor was the mask in the least degree scorched, as if it had been imbedded in heated matter. This tuff is porous; and, when first excavated, is soft and easily worked, but acquires a considerable degree of induration on exposure to the air. Above this lowest stratum is placed, according to Hamilton, 'the matter of six eruptions,' each separated from the other by veins of good soil. In these soils Lippi states that he collected a considerable number of land shells—an observation which is no doubt correct; for many snails burrow in soft soils, and some Italian species descend, when they hybernate, to the depth of five feet and more from the surface. Della Torre also informs us that there is in one part of this superimposed mass a bed of true siliceous lava (*lava di pietra dura*); and, as no such current is believed to have flowed till near 1,000 years after the destruction of Herculaneum, we must conclude that the origin of a large part of the covering of Herculaneum was long subsequent to the first inhumation of the place. That city, as well as Pompeii, was a seaport. Herculaneum is still very near the shore, but a tract of land, a mile in length, intervenes between the borders of the Bay of Naples and Pompeii. In both cases the gain of land is due to the filling up of the bed of the sea with volcanic

* Hamilton, Observ. on Mount Vesuvius, p. 94. London, 1774.

matter, and not to elevation by earthquakes, for there has been no change in the relative level of land and sea. Pompeii stood on a slight eminence composed of the lavas of the ancient Vesuvius, and flights of steps led down to the water's edge. The lowermost of these steps are said to be still on an exact level with the sea.

Conditions and contents of the buried cities.—After these observations on the nature of the strata enveloping and surrounding the cities, we may proceed to consider their internal condition and contents, so far at least as they offer facts of geological interest. Notwithstanding the much greater depth at which Herculaneum was buried, it was discovered before Pompeii, by the accidental circumstance of a well being sunk, in 1713, which came right down upon the theatre, where the statues of Hercules and Cleopatra were soon found. Whether this city or Pompeii, both of them founded by Greek colonies, was the more considerable, is not yet determined; but both are mentioned by ancient authors as among the seven most flourishing cities in Campania. The walls of Pompeii were three miles in circumference; but we have, as yet, no certain knowledge of the dimensions of Herculaneum. In the latter place the theatre alone is open for inspection; the Forum, Temple of Jupiter, and other buildings, having been filled up with rubbish as the workmen proceeded, owing to the difficulty of removing it from so great a depth below ground. Even the theatre is only seen by torchlight, and the most interesting information, perhaps, which the geologist obtains there, is the continual formation of stalactite in the galleries cut through the tuff; for there is a constant percolation of water charged with carbonate of lime mixed with a small portion of magnesia. Such mineral waters must, in the course of time, create great changes in many rocks; especially in lavas, the pores of which they may fill with calcareous spar, so as to convert them into amygdaloids. Some geologists, therefore, are unreasonable when they expect that volcanic rocks of remote eras should accord precisely with those of modern date; since it is obvious that many of those produced in our own time will not long retain the same aspect and internal composition.

Both at Herculaneum and Pompeii, temples have been found with inscriptions commemorating the rebuilding of the edifices after they had been thrown down by an earthquake.* This earthquake happened in the reign of Nero, sixteen years before the cities were overwhelmed. In Pompeii, one-fourth of which is now laid open to the day, both the public and private buildings bear testimony to the catastrophe. The walls are rent, and in many places traversed by fissures still open. Columns are lying on the ground only half hewn from huge blocks of travertin, and the temple for which they were designed is seen half repaired. In some few places the pavement had sunk in, but in general it was undisturbed, consisting of large irregular flags of lava joined neatly together, in which the carriage wheels have often worn ruts an inch and a half deep. In the wider streets, the ruts are numerous and irregular; in the narrower there are only two, one on each side, which are very conspicuous. It is impossible not to look with some interest even on these ruts, which were worn by chariot wheels more than seventeen centuries ago; and, independently of their antiquity, it is remarkable to see such deep incisions so continuous in a stone of great hardness.

Small number of skeletons.—A very small number of skeletons have been discovered in either city; and it is clear that most of the inhabitants not only found time to escape, but also to carry with them the principal part of their valuable effects. In the barracks of Pompeii were the skeletons of two soldiers chained to the stocks, and in the vaults of a country-house in the suburbs were the skeletons of seventeen persons, who appear to have fled there to escape from the shower of ashes. They were found enclosed in an indurated tuff, and in this matrix was preserved a perfect cast of a woman, perhaps the mistress of the house, with an infant in her arms. Although her form was imprinted on the rock, nothing but the bones remained. To these a chain of gold was suspended, and on the fingers of the skeletons were rings with jewels. Against the sides of the same vault was ranged a long line of earthen amphoræ.

* Swinburne and Lalande. Paderni, Phil. Trans. 1758, vol. i. p. 619.

The writings scribbled by the soldiers on the walls of their barracks, and the names of the owners of each house written over the doors, are still perfectly legible. The colours of fresco paintings on the stuccoed walls in the interior of buildings are almost as vivid as if they were just finished. There are public fountains decorated with shells laid out in patterns in the same fashion as those now seen in the town of Naples; and in the room of a painter, who was perhaps a naturalist, a large collection of shells was found, comprising a great variety of Mediterranean species, in as good a state of preservation as if they had remained for the same number of years in a museum. A comparison of these remains with those found so generally in a fossil state would not assist us in obtaining the least insight into the time required to produce a certain degree of decomposition or mineralisation; for, although under favourable circumstances much greater alteration might doubtless have been brought about in a shorter period, yet the example before us shows that an inhumation of seventeen centuries may sometimes effect nothing towards the reduction of shells to the state in which fossils are usually found.

The wooden beams in the houses at Herculaneum are black on the exterior, but, when cleft open, they appear to be almost in the state of ordinary wood, and the progress made by the whole mass towards the state of lignite is scarcely appreciable. Some animal and vegetable substances of more perishable kinds have of course suffered much change and decay, yet the state of preservation of these is truly remarkable. Fishing-nets are very abundant in both cities, often quite entire; and their number at Pompeii is the more interesting from the sea being now, as we stated, a mile distant. Linen has been found at Herculaneum, with the texture well defined; and in a fruiterer's shop in that city were discovered vessels full of almonds, chestnuts, walnuts, and fruit of the 'carubiere,' all distinctly recognisable from their shape. A loaf, also, still retaining its form, was found in a baker's shop, with his name stamped upon it. On the counter of an apothecary was a box of pills converted into a fine earthy substance; and by the side of it a small cylindrical roll

evidently prepared to be cut into pills. By the side of these was a jar containing medicinal herbs. In 1827, moist olives were found in a square glass case, and 'caviare,' or roe of a fish, in a state of wonderful preservation. An examination of these curious condiments has been published by Covelli of Naples, and they are preserved hermetically sealed in the museum there.*

Papyri.—There is a marked difference in the condition and appearance of the animal and vegetable substances found at Pompeii and Herculaneum; those of Pompeii being penetrated by a grey pulverulent tuff, those in Herculaneum seeming to have been first enveloped by a paste which consolidated round them, and then allowed them to become slowly carbonised. Some of the rolls of papyrus at Pompeii still retain their form; but the writing, and indeed almost all the vegetable matter, appear to have vanished, and to have been replaced by volcanic tuff somewhat pulverulent. At Herculaneum the earthy matter has scarcely ever penetrated; and the vegetable substance of the papyrus has become a thin friable black matter, almost resembling in appearance the tinder which remains when stiff paper has been burnt, in which the letters may still be sometimes traced. The small bundles of papyri, composed of five or six rolls tied up together, had sometimes lain horizontally, and were pressed in that direction, but sometimes they had been placed in a vertical position. Small tickets were attached to each bundle, on which the title of the work was inscribed. In one case only have the sheets been found with writing on both sides of the pages. So numerous are the obliterations and corrections, that many must have been original manuscripts. The variety of handwritings is quite extraordinary: nearly all are written in Greek, but there are a few in Latin. They were almost all found in a suburban villa in the library of one private individual; and the titles of four hundred of those least injured, which have been read, are found to be unimportant works, but all entirely new, chiefly relating to music, rhetoric, and cookery. There are two volumes of Epicurus 'On Nature,' and the others are mostly by writers of the same school, only

* Prof. J. D. Forbes, Edin. Journ. of Sci., No. xix. p. 130. Jan. 1829.

one fragment having been discovered, by an opponent of the Epicurean system, Chrysippus. In one of the manuscripts which was in the hands of the interpreters when I visited the museum in 1828, the author indulges in the speculation that all the Homeric personages were allegorical—that Agamemnon was the ether, Achilles the sun, Helen the earth, Paris the air, Hector the moon, &c. If the opinion of some antiquaries be correct that not one-hundredth part of Herculaneum has yet been explored, we may still hope that some rolls of papyrus may yet be found containing some of the lost works of the Augustan age, or of eminent Greek historians and philosophers.

Stabiæ.—Besides the cities already mentioned, Stabiæ, a small town about six miles from Vesuvius, and near the site of the modern Castel-a-Mare (see map of volcanic district of Naples, p. 600), was overwhelmed during the eruption of 79. Pliny mentions that, when his uncle was there, he was obliged to make his escape, so great was the quantity of falling stones and ashes. In the ruins of this place, a few skeletons have been found buried in volcanic ejections, together with some antiquities of no great value, and rolls of papyrus, which, like those of Pompeii, were illegible.

Torre del Greco overflowed by lava.—Of the towns hitherto mentioned, Herculaneum alone has been overflowed by a stream of melted matter; but this did not, as we have seen, enter or injure the buildings, which were previously enveloped or covered over with tuff. But burning torrents have often taken their course through the streets of Torre del Greco, and consumed or enclosed a large portion of the town in solid rock. It seems probable that the destruction of three thousand of its inhabitants in 1631, which some accounts attribute to boiling water, was principally due to one of those alluvial floods which we before mentioned; but, in 1737, the lava itself flowed through the eastern side of the town, and afterwards reached the sea; and, in 1794, another current, rolling over the western side, filled the streets and houses, and killed more than four hundred persons. The main street is now quarried through this lava, which supplied building stones for new houses erected where others had been

annihilated. The church was half-buried in a rocky mass, but the upper portion served as the foundation of a new edifice.

The number of the population when I was first there, in 1828, was estimated at fifteen thousand; and a satisfactory answer may readily be returned to those who enquire how the inhabitants can be so 'inattentive to the voice of time and the warnings of nature,'* as to rebuild their dwellings on a spot so often devastated. No neighbouring site unoccupied by a town, or which would not be equally insecure, combines the same advantages of proximity to Naples, to the sea, and to the rich lands on the flanks of Vesuvius. If the present population were exiled, they would immediately be replaced by another, for the same reason that the Maremma of Tuscany and the Campagna di Roma will never be depopulated, although the malaria fever commits more havoc in a few years than the Vesuvian lavas in as many centuries. The district around Naples supplies one amongst innumerable examples, that those regions where the surface is most frequently renewed, and where the renovation is accompanied, at different intervals of time, by partial destruction of animal and vegetable life, may nevertheless be amongst the most habitable and delightful on our globe, and the remark applies as well to parts of the surface which are the abode of aquatic animals as to those which support terrestrial species. The sloping sides of Vesuvius give nourishment to a vigorous and healthy population of about eighty thousand souls; and the surrounding hills and plains, together with several of the adjoining isles, owe the fertility of their soil to matter ejected by prior eruptions. Had the fundamental limestone of the Apennines remained uncovered throughout the whole area, the country could not have sustained a twentieth part of its present inhabitants. This will be apparent to every geologist who has marked the change in the agricultural character of the soil the moment he has passed the utmost boundary of the volcanic ejections, as when, for example, at the distance of about seven miles from

* Sir H. Davy, Consolations in Travel, p. 66.

Vesuvius, he leaves the plain and ascends the declivity of the Sorrentine Hills.

Yet favoured as this region has been by Nature from time immemorial, the signs of the changes imprinted on it during the period that it has served as the habitation of man may appear in after-ages to indicate a series of unparalleled disasters. Let us suppose that at some future time the Mediterranean should form a gulf of the great ocean, and that the waves and tidal current should encroach on the shores of Campania, as it now advances upon the eastern coast of England; the geologist will then behold the towns already buried, and many more which will evidently be entombed hereafter, laid open in steep cliffs, where he will discover buildings superimposed above each other, with thick intervening strata of tuff or lava—some unscathed by fire, like those of Herculaneum and Pompeii; others half melted down, as in Torre del Greco; and many shattered and thrown about in strange confusion, as in Tripergola, beneath Monte Nuovo. Among the ruins will be seen skeletons of men, and impressions of the human form stamped in solid rocks of tuff. Nor will the signs of earthquakes be wanting. The pavement of part of the Domitian Way, and the temple of the nymphs, submerged at high tide, will be uncovered at low water, the columns remaining erect and uninjured. Other temples which had once sunk down, like that of Serapis, will be found to have been upraised again by subsequent movements. If they who study these phenomena, and speculate on their causes, assume that there were periods when the laws of Nature or the whole course of natural events differed greatly from those observed in their own time, they will scarcely hesitate to refer the wonderful monuments in question to those primeval ages. When they consider the numerous proofs of reiterated catastrophes to which the region was subject, they may, perhaps, commiserate the unhappy fate of beings condemned to inhabit a planet during its nascent and chaotic state, and feel grateful that their favoured race has escaped such scenes of anarchy and misrule.

Yet what was the real condition of Campania during those years of dire convulsion? 'A climate,' says Forsyth, 'where

heaven's breath smells sweet and wooingly—a vigorous and luxuriant nature unparalleled in its productions—a coast which was once the fairy-land of poets, and the favourite retreat of great men. Even the tyrants of the creation loved this alluring region, spared it, adorned it, lived in it, died in it.'* The inhabitants, indeed, have enjoyed no immunity from the calamities which are the lot of mankind; but the principal evils which they have suffered must be attributed to moral, not to physical, causes—to disastrous events over which man might have exercised a control, rather than to the inevitable catastrophes which result from subterranean agency. When Spartacus encamped his army of ten thousand gladiators in the old extinct crater of Vesuvius, the volcano was more justly a subject of terror to Campania than it has ever been since the rekindling of its fires.

* Forsyth's Italy, vol. ii.

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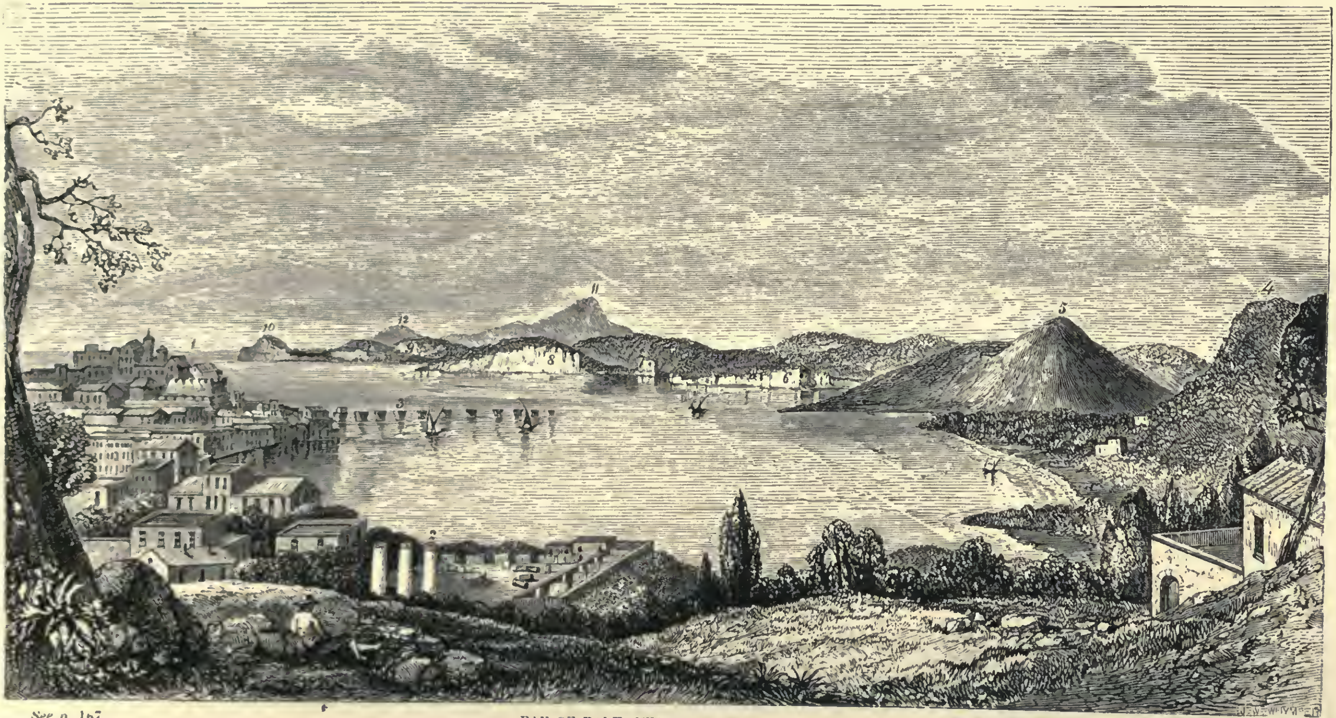


See p. 167.

BAY OF BAIÆ, NEAR NAPLES.

(Sir W. Hamilton, Campi Phlegræi, Plate 26.)

1. Puzzuoli. 2. Temple of Serapis. 3. Caligula's Bridge. 4. Monte Barbaro. 5. Monte Nuovo. 6. Baths of Nero. 7. Baiæ. 8. Castle of Baiæ. 9. Bauli. 10. Cape Misenum. 11. Monte Eporneo in Ischia. 12. South Part of Ischia.

CHAPTER XXVI.

ETNA.

EXTERNAL PHYSIOGNOMY OF ETNA—LATERAL CONES—THEIR SUCCESSIVE OBLITERATION—MARINE STRATA AT BASE OF ETNA OF NEWER PLIOCENE DATE—OLDEST VOLCANIC ROCKS OF SAME DATE—FOSSIL PLANTS OF LIVING SPECIES IN ANCIENT TUFFS OF ETNA—VAL DEL BOVE ON THE EASTERN FLANK OF ETNA—INTERNAL STRUCTURE OF THE MOUNTAIN AND PROOFS OF A DOUBLE AXIS OF ERUPTION—WANT OF PARALLELISM IN THE ANCIENT LAVAS—DIKES IN THE VAL DEL BOVE, THEIR FORM AND COMPOSITION—TRUNCATION OF THE GREAT CONE—ERUPTIONS OF ETNA OF HISTORICAL DATE—ERUPTION OF MONTI ROSSI, 1669—SCENERY OF THE VAL DEL BOVE—ERUPTIONS OF 1811 AND 1819—THAT OF 1852—CHANGES WHICH IT HAS EFFECTED IN THE VAL DEL BOVE—CASCADES OF LAVA IN THE VAL DI CALANNA—INCLINED LAVA OF CAVA GRANDE—FLOOD PRODUCED BY THE MELTING OF ICE IN 1755—GLACIER PRESERVED BY A COVERING OF LAVA—ANCIENT VALLEYS OF ETNA—ANTIQUITY OF THE CONE OF ETNA.

External physiognomy of Etna.—Next to Vesuvius, our most authentic records relate to Etna, which rises near the sea in solitary grandeur to the height of nearly 11,000 feet.* The base of the cone is almost circular, and 87 English miles

* In 1815, Captain Smyth ascertained, trigonometrically, that the height of Etna was 10,874 feet. The Catanians, disappointed that their mountain had lost nearly 2,000 feet of the height assigned to it by Recupero, refused to acquiesce in the decision. Afterwards, in 1824, Sir J. Herschel, not being aware of Captain Smyth's conclusions, determined by careful barometrical measurement that the height was 10,872½ feet. This singular agreement of results so differently obtained was spoken of by Herschel as 'a happy accident;' but Dr. Wollaston remarked that 'it was one of those accidents which would not have happened to two fools.'

in circumference; but if we include the whole district over which its lavas extend, the circuit is probably twice as great.

The cone is divided by nature into three distinct zones, called the *fertile*, the *woody*, and the *desert* regions. The first of these, comprising the delightful country around the skirts of the mountain, is well cultivated, thickly inhabited, and covered with olives, vines, corn, and fruit trees. Higher up, the woody region encircles the mountain—an extensive forest six or seven miles in width, affording pasturage for numerous flocks. The trees are of various species, the chestnut, oak, and pine being most luxuriant; while in some tracts are groves of cork and beech. Above the forest is the desert region, a waste of black lava and scoriæ, which terminates upwards in a kind of table-land, from which rises the principal cone, 1,100 feet high, emitting continually steam and sulphureous vapours, and in the course of almost every century several streams of lava.

Cones produced by lateral eruption.—The most grand and original feature in the physiognomy of Etna is the multitude of minor cones which are distributed over its flanks, and which are most abundant in the woody region. These, although they appear but trifling irregularities when viewed from a distance as subordinate parts of so imposing and colossal a mountain, would, nevertheless, be deemed hills of considerable altitude in almost any other region. Without enumerating numerous monticules of ashes thrown out at different points, there are about 200 of these secondary volcanos as laid down in Von Waltershausen's map within a circuit twenty geographical miles in diameter, having the summit of Etna as a centre. Outside of this circular area are a few other modern cones of large size, such as the double hill near Nicolosi, called Monti Rossi, formed in 1659, which is 450 feet high, and two miles in circumference at its base. Although this hill somewhat exceeds in size Monte Nuovo, described in the twenty-fourth chapter, it only ranks as a cone of the second magnitude amongst those produced by the lateral eruptions of Etna. Monte Minardo, near Bronte, on the east of the great volcano, is upwards of 700 feet in height.

On looking down from the lower borders of the desert

region, these minor volcanos present us with one of the most delightful and characteristic scenes in Europe. They afford every variety of height and size, and are arranged in beautiful and picturesque groups. However uniform they may appear when seen from the sea, or the plains below, nothing can be more diversified than their shape when we look from above into their craters, one side of which is generally broken down. There are, indeed, few objects in nature more picturesque than a wooded volcanic crater. The cones situated in the higher parts of the forest zone are chiefly clothed with lofty pines; while those at a lower elevation are adorned with chestnuts, oaks, and beech trees.

Successive obliteration of these cones.—The history of the eruption of Etna, imperfect and interrupted as it is, affords us, nevertheless, much insight into the manner in which a large part of the mountain has successively attained its present magnitude and internal structure. The cone from which the eruptions at the summit now proceed, has more than once been destroyed either by explosion or engulphment, and has been as often reproduced. The great platform (No. 2, Plate V., and *a*, *b*, *c*, fig. 85, p. 20) seems to have resulted from the truncation of the ancient conical mountain, the uppermost part of which has disappeared during a succession of such catastrophes, leaving a comparatively level ground from which the modern cone now springs.

By far the greater number of eruptions proceed from the great crater *a*, fig. 85, and from lateral openings in the desert region. When hills are thrown up lower down or in the middle zone, and project beyond the general level, they gradually lose their height during subsequent eruptions; for when lava descending from the upper parts of the mountain encounters any of these hills, the stream is divided, and flows round them so as to elevate the gently sloping grounds from which they rise. In this manner a deduction is often made at once of twenty or thirty feet, or even more, from their height. Thus, one of the minor cones, called Monte Peluso, was diminished in altitude by a great lava stream which encircled it in 1844; and another current has recently taken the same course—yet this hill still remains 400 or 500 feet high.

There is a cone called Monte Nucilla near Nicolosi, round the base of which several successive currents have flowed, and showers of ashes have fallen in historical times, till at last, during an eruption in 1536, the surrounding plain was so raised, that the top of the cone alone was left projecting above the general level. Monte Nero, situated above the Grotta dell' Capre, was in 1766 almost overflowed by a current: and Monte Capreolo afforded, in the year 1669, a

Fig. 76.

View of Etna from the summit of the limestone platform of Primosole, looking north.

a. Highest cone.
b. Montagnuola.
c. Monte Minardo, with smaller lateral cones above.
d. Town of Licodia dei Monaci.
e. Argillaceous and sandy beds with marine shells, nearly all of living Mediterranean species, and with associated and contemporaneous volcanic rocks.
f. Escarpment of stratified subaqueous volcanic tuff, &c., north-west of Catania.
g. Town of Catania.
h, i. Dotted line expressing the highest boundary along which the marine strata are occasionally seen. They reach at Catira, 4 miles north of Catania, a height of about 1,258 English feet above the level of the sea.
k. Plain of Catania.
l. Limestone platform of Primosole of the Newer Pliocene period.
m. La Motta di Catania.

curious example of one of the last stages of obliteration; for a lava stream, creeping along the top of a ridge which had been built up by the continued superposition of successive lavas, flowed directly into the crater, and nearly filled it. The lava, therefore, of each new lateral cone tends to detract from the relative heights of lower cones above their bases; so that the flanks of Etna, sloping with a gentle inclination, envelope in succession a great multitude of minor volcanos, while new ones spring up from time to time.

Marine strata and volcanic rocks of Etna of Newer Pliocene date.—In the annexed outline of Etna and its environs, which I made in 1828 from the platform of tertiary limestone of Primosole, the summit of the volcano is seen 24 geograph-

ical miles distant in a straight line. At our feet lies the alluvial plain of Catania (*k*) 6 miles broad, through which the Simeto runs, and which is bounded on the north by an undulating country, *e, e*, composed for the most part of a marine tertiary deposit of Newer Pliocene age.

The district composed of it near Catania which is provincially called 'Terra Forte,' must have emerged from beneath the sea at a period of very modern date geologically speaking; for not only are almost all the fossil shells, included in the clays, of recent species, but the argillaceous beds themselves are capped at the height of nearly 1,000 feet by two deposits, in one of which near the sea all the shells are of living species, while the other consists of rounded pebbles of limestone and other rocks evidently once brought down from the interior by the Simeto and deposited in its delta, which delta was afterwards uplifted together with the subjacent clay as well as the neighbouring mass of Etna and the sea-coast at its base. In the old alluvium here adverted to, the bones of elephants and other extinct mammalia have been found at several points. The line *h, i*, expresses the level at which the marine Newer Pliocene formation crops out irregularly from beneath the modern streams of volcanic matter which are gradually encroaching upon it and concealing it more and more from view. Sometimes it cannot be traced higher than 600 feet, but at one place called Catira, 4 miles north of Catania, the marine clays have been detected at the height of 1,258 English feet above the level of the Mediterranean. At that point and along the adjoining coast, as at Aci Castello and at Trezza opposite the Cyclopean islands, and at Nizzeti a mile and a half north-west of Trezza, the fossiliferous clays are associated with contemporaneous basaltic and other igneous products, the most ancient monuments of volcanic action within the region of Etna. By these eruptions the foundations of the great volcano may be said to have been laid in the sea when the present site of Etna was a bay of the Mediterranean. The fossil shells therefore found in these clays are of great interest in settling the chronology of the older part of the mountain. Out of 65 species which I myself collected in 1828 M. Deshayes considered 4 to be

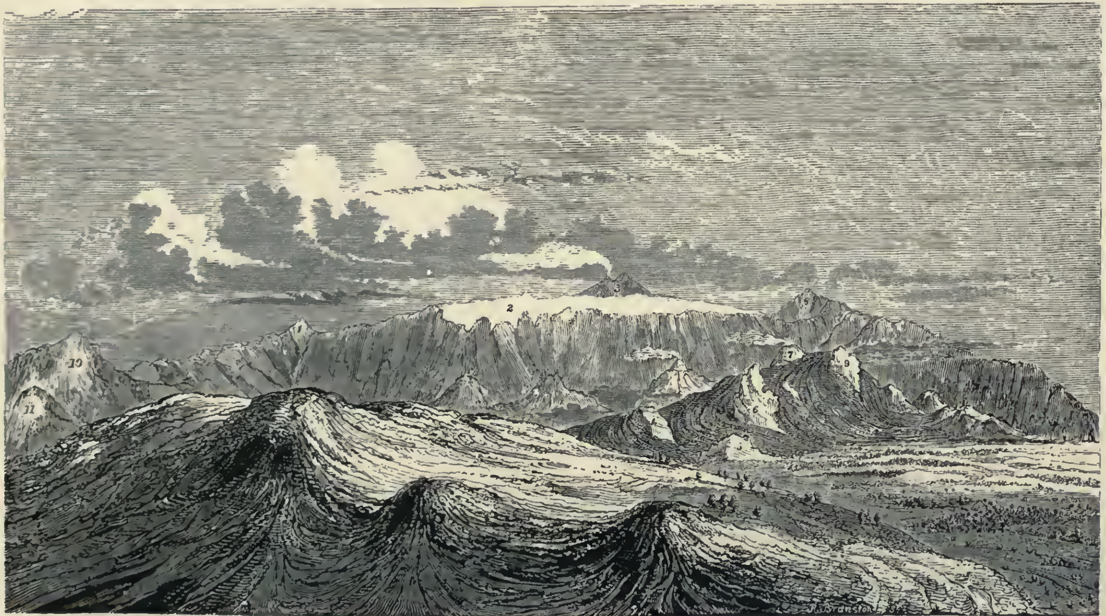
extinct and the rest now common in the Mediterranean. Philippi in 1844 obtained from the same district 76 species, of which only 3 were extinct, while he found that a larger number (109) from Cefali in the suburbs of Catania yielded a proportion of about 6 per cent. of extinct as compared to living species. A still larger collection of 142 species of shells which Dr. Aradas kindly lent to me in 1858 yielded 8 per cent. of extinct species.* But these results are not so inconsistent as they at first appear, because all the abundant species (except *Buccinum semistriatum*, already mentioned as the only extinct shell out of 100 found in the ancient tuffs of Somma) are now living in the neighbouring sea, whereas nearly all the lost species are so exceedingly rare that sometimes single individuals of them have alone been found. Nevertheless I regard the most ancient part of Etna as somewhat older than the foundations of Vesuvius, and if I were asked what relation the tertiary strata near Catania bear in point of age to our British formations, I should answer that they are about the age of the Norwich crag. In reference therefore to the Glacial period I consider the oldest eruptions of Etna as of older date than the era of greatest cold in central and northern Europe.

The reader must not suppose that the marine strata with the associated basaltic rocks were first formed and then raised to their present height above the level of the sea, and that the great subaërial cone of Etna was a superstructure of later date; for there is reason to believe that a general and gradual upheaval of the foundations of Etna, together with the neighbouring country, was always going on during the long period of supra-marine eruptions. And this slow upward movement is probably still continuing, since raised beaches of sands with littoral shells of living species often retaining their colour are observed at the eastern base of Etna skirting the shore, and there are also lines of inland cliff cut in the tertiary strata and in the volcanic tuffs bearing witness to successive alterations in the relative level of sea and land.

Fossil plants of living species in ancient tuffs of Etna.—We

* See 'Mode of Origin of Mount Etna,' by the Author, Phil. Trans. Part II. for 1858, p. 778.

Plate V.



VIEW LOOKING UP THE VAL DEL BOVE, ETNA.

have rarely an opportunity of determining the exact nature of the vegetation which covered the mountain when some of the oldest showers of volcanic ashes were poured out; but there are some stratified tuffs at Fasano near Catania replete with fossil leaves which throw some light on this subject. I obtained several species of land-plants from these tuffs which were determined by Professor Heer to belong to species now living in Sicily. Among others were the sweet bay, *Laurus nobilis*, the common myrtle, *Myrtus communis*, and the Mastick tree, *Pistachia lentiscus*.

Val del Bove on the eastern flank of Etna.—Etna, when viewed whether from the north or south, is of a very symmetrical form, but on its eastern side it is intersected by a deep valley called the Val del Bove, the head or upper part of which is bounded by a precipice between 3,000 and 4,000 feet high, which begins immediately below the eastern margin of that highest platform which was before mentioned (p. 3) as having been produced by the truncation of the great cone. The annexed view, Plate V., taken from a drawing which I made in November, 1828, will give the reader some idea of this precipice below the platform No. 2, which was at that time covered with snow.

The great lava currents of 1811 and 1819 are seen pouring down from the higher parts of the Val del Bove, overrunning the forests of the great valley, and rising up in the foreground on the left with a rugged surface, on which many hillocks and depressions appear, such as often characterise a lava current before it has ceased to flow as well as after its consolidation.

The small cone, No. 7, was formed in 1811, and was still smoking when I saw it in 1828. The other small volcano to the left, from which vapour is issuing, was, I believe, one of those formed in 1819.

The following are the names of some of the points indicated in the sketch:—

1. Montagnuola.	5. Finocchio.	9. Musara.
2. Torre del Filosofo.	6. Capra.	10. Zoccolaro.
3. Highest cone.	7. Cone of 1811.	11. Rocca di Calanna.
4. Lepra.	8. Cima del Asino.	

Description of Plate VI.—The second view (Pl. VI.) represents the same valley as seen from above, or looking directly from the Val del Bove, from the summit of the principal crater formed in 1819.*

The circular form of the Val del Bove is well shown in this view (Pl. VI.) To the right and left are the lofty precipices which form the southern and northern sides of the great valley, and which are intersected by dikes projecting in the manner afterwards to be described. In the distance appears the 'fertile region' of Etna, extending like a great plain along the sea-coast.

The spots particularly referred to in the plate are the following:—

a. Cape Spartivento, in Italy, of which the outline is seen in the distance.

b. The promontory of Taermino, on the Sicilian coast.

c. The river Alcantra.

d. The small village of Riposto.

e. Valley of Calanna.

f. The town of Aci Reale.

g. Cyclopean islands, or 'Faraglioni,' in the Bay of Trezza.

h. The great harbour of Syracuse.

i. The city of Catania, near which is marked the course of the lava which flowed from the Monti Rossi in 1669, and destroyed part of the city.

k. The Lake of Lentini.

l. To the left of the view is the crater of 1811, which is also shown at No. 7, in Plate V.

m. Rock of Musara, also seen at No. 9, in Plate V.

The Val del Bove is of truly magnificent dimensions, a vast amphitheatre 4 or 5 miles in diameter, surrounded by nearly vertical precipices, the loftiest being at the upper or eastern end, where, as before stated, they are between 3,000 and 4,000 feet high, and the others on the north and south side diminishing gradually from that height to 500 feet as they extend eastward. The feature which first strikes the geologist as distinguishing the boundary cliffs of this valley, is the prodigious multitude of vertical dikes which are seen in all directions traversing the volcanic beds. The circular form of the great chasm, and the occurrence of so many dikes, amounting perhaps to several thousands in number, cannot fail to recall to the mind of everyone familiar with Vesuvius the phenomena of the Atrio del Cavallo, although

* This view is taken from a sketch made by Mr. James Bridges, corrected after comparison with several sketches of my own. I am unable to point out the precise spot which this crater would occupy in the view represented in Plate V.; but I conceive that it would appear in the face of the great precipice, near which the smoke issuing from the cone No. 7 is made to terminate. There are many ledges of rock on the face of that precipice where eruptions have occurred.

Plate VI.

VIEW OF THE VAL DEL BOVE, ETNA, AS SEEN FROM ABOVE, OR FROM THE CRATER OF 1819.

the Val del Bove is on a scale as far exceeding that of Somma as Etna surpasses Vesuvius in magnitude.

Internal structure of the mountain and proofs of a double axis of eruption.—When I first examined Etna in 1828, I supposed that the boundary walls of the great amphitheatre displayed such an arrangement of the beds as showed that the structure of that part of the mountain was very different from that which the escarpment of Somma exhibits. I imagined that the sloping away of the strata from a central axis to all points of the compass, or what has been called quaquaversal dip, was wanting in the Val del Bove. But when I revisited the same district in 1857–8,* I discovered that the lower portion of the volcanic beds exposed to view in the great precipices *k*, *i*, at the head of the valley *h*, *i*, *k*, of the section fig. 78, page 12, dipped steeply to the west, and this arrangement of the strata, together with that observed in the other cliffs bounding the valley, can only be explained by assuming that there was once a great centre of eruption at or near the point in the annexed map (fig. 77, p. 10) which I have marked with a cross as indicating the axis of Trifoglietto. The direction of the arrows *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*, indicate the various points of the compass towards which the strata have been observed to be inclined. I was accompanied in 1857 by Signor G. G. Gemmellaro, when we made out this quaquaversal dip, and came to the opinion that the point marked with a cross or the axis of Trifoglietto had been an ancient centre of eruption.†

In confirmation of this theory, Baron S. von Waltershausen has observed that there is an ancient set of greenstone dikes, thirteen or more in number, which radiate from the point or axis alluded to, and are seen traversing the surrounding precipices. These greenstone dikes are distinguishable by their mineral composition from those of more modern doleritic lava which radiate from the present great centre of eruption or the summit of Etna. This centre may be called, from the modern name of the mountain, the axis of Mongi-

* See Paper on Mount Etna by the Author, Phil. Trans. Part II. for 1858.

† I was not then aware that Baron S. von Waltershausen had previously come to the same conclusion; for that part of his Atlas in which he announced this opinion was not published till after my return to England.

Fig. 77.


M
SUMMIT OF ETNA
VALLE DEL LEONE
SERRA DELLE CONCAZZE
CASA INGLESE
TORRE
VAL DEL BOVE
Rocca Musara
i
Rocca Capra
M. CALIATO
LAVA OF 1689
CAVA GRANDE
h
M. FINOCCHIO
g
l
SERRA GIANNICOLA
1852
PIANO DEL LAGO
k
CISTERNA
a
AXIS OF TRIFOGLIETTO
b
f
M. CALANNA
MILO
MONTAGNUOLA
ROCCA DEL CORVO
c
d
e
ZOCCOLARO
SALTO
VALLE DI CALANNA
SCHIENA DELL' ASINO
SERRA DEL SOLFIZIO
VALLE DEL TRIPODO
VALLE DEL ZAPPINI
V. DI S. GIACOMO
CAVA SECCA
ZAFARANA
N
W
E
S
MAP OF PART OF MT. ETNA
SCALE OF ENGLISH MILES.
Arrows from a to k indicate the dip of the Beds.

Description of Fig. 77.—(Map of Etna, p. 10.)

Ground plan of the Val del Bove, showing the dip of the beds on opposite sides of the axis of Trifoglietto.

Arrows *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*, showing the dip of the beds in opposite directions from the centre of eruption or axis of Trifoglietto.

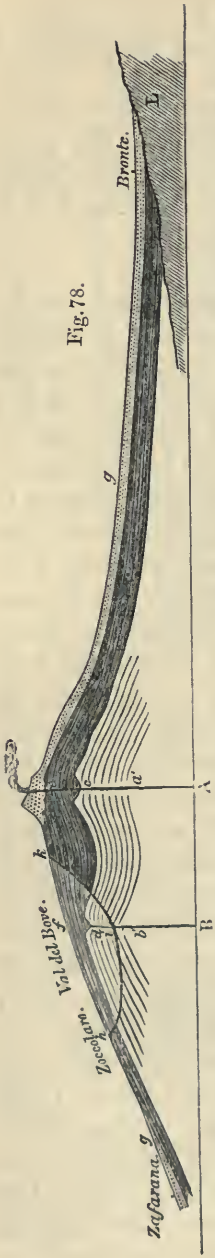
k. Arrow showing the direction of the dip of the beds in the Cisterna (see also *k* in the section fig. 78), where they are inclined 6° south-east, whereas the beds in the lower parts of the same precipice as indicated by the arrow *b*, dip in quite a different direction, or at an angle of more than 20° to the west.

l. Horizontal beds in the great precipice above the Serra Giannicola, resting on beds of trachyte and trachytic tuff and conglomerate, which last dip at angles of from 20° to 28° N.W. as indicated by the arrow *a*.

M. N. Line of section of fig. 78.

bello. In 1858, when I paid a third visit to the Val del Bove, I found that there was a great thickness of beds (*l*, of Map fig. 77), in that part of the precipice between the Piano del Lago and Giannicola, which are horizontal—a fact perfectly reconcilable with the theory that the structure of Mount Etna is due to its having been formed by the pouring out of lava and scoriæ from two great distinct centres of eruption before alluded to, viz., that of Trifoglietto and that of Mongibello; the latter having eventually obtained such an ascendency as to overwhelm the products of the former, and reduce the whole mountain to one symmetrical cone, broken subsequently by the great chasm of the Val del Bove on its eastern side, above described, a chasm of comparatively modern date. The accompanying section, p. 12, will explain the theory of the structure of Etna above alluded to, namely the hypothesis of a double axis by which all the dips in opposite directions in the Val del Bove, apparently so complicated, together with the horizontality of the beds immediately below the edge of the Piano del Lago, are found to be resolvable into a very simple arrangement, such as is exemplified in not a few of the great Javanese volcanos described by Junghuhn. That author has particularly called attention to the fact, that when there are two centres of eruption in the same volcanic mountain, there is a certain area between them, which he calls a saddle, where the beds of lava, or the showers of ashes, are level or horizontal. Among other instances he alludes to a saddle connecting the twin cones of Gede and Panggerango which is 7,870 feet high. The largest of the two cones, although truncated like Etna, is 9,226 feet high, and the lesser cone has a deep valley on one

Fig. 78.



Ideal section of Mount Etna, from West 20° N. to East 20° S., to illustrate the theory of a double axis of eruption. See M. N. Map, Fig. 77.

A. Axis of Mongibello.
B. Axis of Trifoglietto.
a', *c*, *b'*, *i*, *d*. Older lavas, chiefly trachytic.
c, *e*, and *d*, *f*. Lavas, chiefly doleritic, poured out from A after the axis or focus B was spent, and before the origin of the Val del Bove.
g, *g*. Scoriæ and lavas of later date than the Val del Bove.

h, *i*, *k*. Val del Bove. The faint lines represent the missing rocks.
N.B. In the section between *i* and *k* it will be seen that the beds at the base, or near *i*, dip steeply away from the Val del Bove: those in the middle, or below *k*, are horizontal, and those at top, or at *k*, dip gently towards the Val del Bove (see pp. 9 and 13).
L. Older tertiary and sandy rocks, chiefly sandstones.

side comparable to the Val del Bove. In the case of Etna we are unable to decide which of the two foci, A or B, fig. 78, gave vent to the earliest eruptions, but it is clear that after B (or the focus of Trifoglietto) was spent, the main vent of Mongibello continued in full vigour, and overwhelmed with its lavas and scoriæ the minor cone *d*, *i*, until it reduced the whole to one slope *k*, *f*, *h*. Subsequently the chasm called the Val del Bove, *h i k*, was formed, chiefly I presume by explosions similar to those which are supposed, in Vol. I. p. 631, to have removed the old central portion of Somma before the modern cone of Vesuvius was built up.

The arrangement of the beds seen between *k* and *i*, fig. 78, in the great precipice at the head of the Val del Bove, is of peculiar geological interest, more especially the horizontality of those beds of lava which are shaded with a dark tint immediately below *k*. In the entire absence of dip which they exhibit, they are strikingly contrasted with lower beds seen in

the same section in the Serra Giannicola, which are highly inclined. In order to study the horizontal beds, I made two descents of the great precipice at different points previously examined by very few geologists, and observed a remarkable resemblance of one of the old lava currents with the lava of 1669, which overflowed some level ground in the neighbourhood of Catania, where there had been a rich vegetation. The vegetable soil was then turned or burnt into a layer of red-brick-coloured stone, reminding me of the red bands which separate so many of the lavas in Madeira. Midway between the top and bottom of the great precipice, at a place called Teatro Grande, the ancient lava current is seen, which had evidently cooled on a flat surface, and the lower scoriaceous part of which reposed on a red band of burnt soil, over which it had poured. Overlying the bottom scoriæ was a central mass of stony lava no less than *forty feet* thick, divided by vertical rents, so as to be almost columnar, and above this again was the usual upper scoriaceous and highly vesicular division of the current. No hypothesis, except that of the double axis, can give even a plausible explanation of the position of this powerful current, which must have cooled on a flat surface. But the phenomena are quite reconcilable with the former existence at this point of a saddle between the cones.

When treating of Vesuvius, in the first volume, p. 634, I gave the reader an account of the theory of elevation craters as it has been called, to which some geologists have attributed the high inclination of the lavas of Somma, which dip outwards in all directions from a central axis. The structure of Mount Etna has been referred by partisans of the same school to a similar movement of upheaval, which caused all the volcanic formations previously horizontal to be suddenly uplifted into a mountain mass, so as to assume a conical form, the beds of lava and scoriæ being made to dip away in all directions from the axis of upheaval. Even if it were true that the alternate scoriaceous and stony beds exhibited a quaquaversal dip, many unanswerable objections might be offered to the above-mentioned hypothesis. Among others, I may mention the impossibility of imagining that so large

a proportion of the dikes of different ages should be so nearly vertical as they are found to be. But as I have dwelt so long on this subject on a former occasion, I will merely say here, in favour of the theory of eruption as opposed to that of upheaval, that one cone formed by eruption may and often does embrace and bury a contiguous cone of older date and of similar origin; whereas a cone of upheaval, even if we grant that the volcanic forces ever give rise to such a structure, cannot be conceived to envelope an older cone.

Want of parallelism in the ancient lavas.—It will be useful, however, to point out in detail some features in the shape

Fig. 79.

Stony layers in the northern escarpment of the Val del Bove in the Serra di Cerrita, part of the Concazze (see Map, fig. 77), where the *precipice* is 1,000 feet high.

a. Vertical section of rock 40 feet.
b, c. Beds to the westward in the same plane as the thickest part of *a*.
d. Same bed as *a* thinning out westward to a thickness of 4 or 5 feet at a distance of a few hundred yards from *a*.

and structure of the beds which are intersected in the cliffs of the Val del Bove, in order to show that they are not uniform in thickness, and that they by no means preserve everywhere that perfect parallelism to each other which has been ascribed to them. They present, it is true, to the eye, a great appearance of regularity when viewed as a whole and from a distance, but when more closely inspected, they are found to be variable, both in thickness and in their dip, as much so as we have any right to expect in currents which have flowed down the sides of a steeply sloping cone like Etna from some opening at or near the summit. The annexed diagrams will explain the appearance of the lavas and scoriæ at many points in the north and south walls of the Val del Bove, where they are laid open to view in vertical sections.

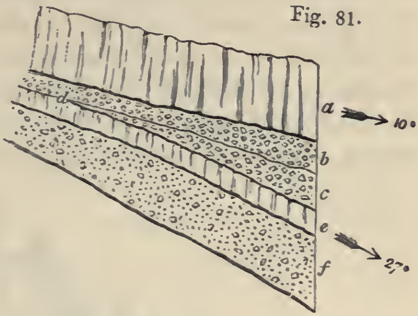
Fig. 80.

Non-parallel beds of stony lava in the Concazze, or part of the northern escarpment of the Val del Bove.

Vertical distance from *a* to *b* about 60 feet. Incoherent tuffs and scoriæ intervene between the solid beds here figured.

As the continuity of many of the beds in the boundary cliffs of the Val del Bove has been thought by some to be opposed to the theory of their having flowed in succession one over the other down the sloping sides of a great cone, I may remark, that provided we behold a section running in the same direction as the original course of the currents, we have every reason to expect them to be continuous for several miles. As to their dip, even if it amount to 20° or 30°, there is no reason for concluding, as I shall show in the sequel, that they may not have been originally inclined at such high angles.

Fig. 81.

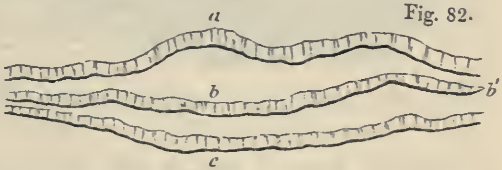


Beds of doleritic lava and scoriæ in the Serra del Solfizio, south side of the Val del Bove.

a. Bed of stony lava 12 feet thick, inclined at an angle of 10°.
b. Bed of scoriæ with angular fragments of scoriaceous lava 5 feet thick.
c. Bed of similar materials, but coarser, thinning out at *d.*
e. Bed of basaltic lava, 3 feet in its greatest thickness, and dipping at an angle of 27° (or 17° degrees steeper than *a*).
f. Fragmentary scoriaceous bed 10 feet thick, having a similar dip with many others which underlie it.

I may here remark, that I saw no signs of buried lateral cones laid open by the grand sections exhibited in the cliffs of the Val del Bove. Such buried cones are distinctly to be seen in some inland ravines and in sea-cliffs in Madeira, and their absence in the Val del Bove implies that the great period of lateral eruptions was subsequent in date to the origin of that valley.

Fig. 82.



Curvatures of lava in the hill of Zoccolaro, at the eastern extremity of the Serra del Solfizio.

a, b, c. Three beds of lava varying in thickness from 4 to 6 feet, and separated by incoherent matter.
b thins out at *b′*.
a and *c* are 40 feet apart in the middle of this section, and come within 12 and 14 feet of each other at the two extremities of the same.

Dikes in the Val del Bove.—I have already alluded to a set of dikes of greenstone or diorite, observed by Waltershausen to converge in the supposed centre of eruption or axis of Trifoglietto (see p. 11). A much greater number of dikes or vertical walls of lava radiate from the modern centre of eruption, or that of Mongibello. They consist chiefly of dolerite or greystone, intermediate between trachyte and basalt,—the trachi-dolerites of some geologists. They vary

Fig. 83.

Dikes at the base of the Serra del Solfizio, Etna.

in breadth from 2 to 20 feet and upwards, and usually project from the face of the cliffs, as represented in the annexed drawing (fig. 83). They consist of harder materials than the strata which they traverse, and therefore waste away less rapidly under the influence of that repeated congelation and thawing to which the rocks in this zone of Etna are exposed. The dikes are, for the most part, vertical, but sometimes they run in a tortuous course through the tuffs and breccias, as represented in fig. 84.

The dikes are most numerous near the head of the Val del

Bove, or near the two ancient centres of eruption before alluded to as the axes of Trifoglietto and Mongibello. They continue to abound throughout that zone of the mountain where lateral eruptions are frequent, but below that level they become extremely rare, as in the valley of Calanna, for example, in which the section of the Val del Bove is continued. Still lower in the same easterly direction, as in the valley of San Giacomo for example, none occur. The rarity or absence of dikes as we recede from the great centres of eruption, is precisely what we might have expected if the vertical fissures now filled with solid rock were once the channels which gave passage to lava currents. Some of the dikes blend at their termination upwards with currents of lava, so that they stop short in their vertical direction, and do not cut through the higher currents of lava which were of a date posterior to the dikes.

Fig. 84.

Tortuous veins of lava at Punto di Giumento, Etna.

We know not how large a quantity of modern lava may have been poured into the bottom of the Val del Bove, yet we perceive that eruptions breaking forth near the centre of Etna have already made no small progress in filling up this great hollow. Even within the memory of persons now living, the rocks of Musara and Capra have, as before stated, lost much of their height and picturesque grandeur by the piling up of recent lavas round their base, and the great chasm has intercepted many streams which would otherwise have deluged the fertile region below. The volcanic forces are now labouring, therefore, to repair the breach caused probably by one or more paroxysmal eruptions of ancient date on one side of the great cone; and unless their energy should decline, or a new sinking take place, they may in time efface this inequality. In that event, the restored portion will always be uncomformable to the more ancient part, yet it will consist, like it, of alternating beds of lava and scoriæ,

which, with all their irregularities, will have a general slope from the centre and summit of Etna towards the sea.

Origin of the Val del Bove.—It will be seen by the ideal section given in fig. 78, p. 12, that I suppose the modern centre of eruption A (that of Mongibello), to have overwhelmed the ancient lateral cone formed by B, so as to reduce the whole mountain to a symmetrical form, the present valley *k*, *i*, *h* having then no existence. In what manner this enormous gulf was formed has been a fertile subject of conjecture. So late as the year 1822, as we shall see in the next chapter, during a violent earthquake and volcanic eruption in Java, one side of the mountain called Galongoon, which was covered by a dense forest, became an enormous gulf in the form of a semicircle. The new cavity was about midway between the summit and the plain, and surrounded by steep rocks.

It will be shown that in that instance vast quantities of boiling water and mud were thrown up like a waterspout, and great blocks of basalt were projected to a distance of 7 miles, and ashes and lapilli of the size of nuts as far as 40 miles. Numerous villages 24 miles distant from the centre of eruption were completely buried, implying that the solid matter ejected by the explosive power of steam was voluminous enough to account for the formation of the new cavity, vast as were its dimensions.

It will be also seen in the thirtieth chapter, that in the year 1772, Papandayang, the largest volcano in the island of Java, lost 4,000 feet of its height, at the same time that 40 villages, spread over an area 14 miles in length and 6 in breadth, were destroyed. According to the earlier accounts they were engulphed, and the truncation of the cone was attributed to subsidence; but the subsequent investigations of Junghuhn about seventy years after the explosion have shown that the villages were overwhelmed by volcanic sand and scoriæ, under which they now lie buried; and it cannot be doubted that the loss of height of the great cone, attributed to subsidence, was caused in great part at least by explosion. The summit of Carguairazo, one of the loftiest of the Andes of Quito, is said to have 'fallen in' on July 19, 1698, and

another cone of still greater altitude in the same chain, called Capac Urcu, was, according to tradition, truncated a short time before the conquest of America by the Spaniards. It is possible that when the lava is rising to the summit of such cones the foundations of parts of the volcanic structure may be undermined and melted, so that one part after another of the walls of the highest crater may sink down before the principal escape of gas and the ejection of scoriæ take place.

In the year 1792 a small circular tract called the Cisterna (see Map, fig. 77, p. 10), situated on the edge of the platform from which the highest cone of Etna rises, sank down to the depth of about 40 feet, leaving a chasm on all sides, of which a vertical section is now seen of alternating stony lavas and scoriæ. It is conceivable, therefore, that parts of the area of the Val del Bove may, in like manner, have fallen in during earthquakes; but I think it probable that by far the greater portion of the huge cavity was caused by explosions of pent-up vapours escaping from subterranean fissures, during one or more lateral eruptions connected perhaps with a temporary revival of the ancient focus of eruption which I have called the axis of Trifoglietto.

Eruptions of Etna of historical date.—Truncation of the great cone.—What I have hitherto said of the first existence of Etna as a submarine volcano, the building up of the sub-aërial part of the mountain by the pouring out of lava and scoriæ from two principal centres, the accompanying general upheaval of the whole mass above the level of the sea, and the probable origin of the Val del Bove, has been entirely founded on geological inferences from the internal structure of the mountain.

We may next turn to history and enquire what changes are recorded to have taken place since the volcano was an object of interest to the civilised world.

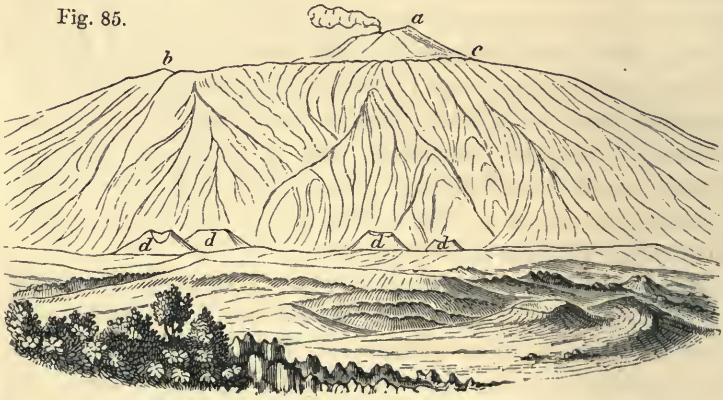
Etna appears to have been in activity from the earliest times of tradition; for Diodorus Siculus mentions an eruption which caused a district to be deserted by the Sicani before the Trojan war. Thucydides informs us, that in the sixth year of the Peloponnesian war, or in the spring of the year 425 B.C., a lava stream ravaged the environs of Catania, and

this he says was the third eruption which had happened in Sicily since the colonisation of that island by the Greeks.* The second of the three eruptions alluded to by the historian took place in the year 475 B.C., and was that so poetically described by Pindar, two years afterwards, in his first Pythian ode:—

> κιων
> Δ' οὐρανια συνεχει
> Νιφοεσσ' Αἰτνα, πανετες
> Χιονος ὀξειας τιθηνα.

In these and the seven verses which follow, a graphic description is given of Etna, such as it appeared five centuries

Fig. 85.



Truncated appearance of the summit of Etna on the north-west side, as seen from near Bronte.—From Sartorius von Waltershausen's Atlas, plate 2.

a. Modern cone. *b, c.* Margin of highest platform. *d.* Minor cones.

before the Christian era, and such as it has been seen when in eruption in modern times. The poet is only making a passing allusion to the Sicilian volcano, as the mountain under which Typhæus lay buried, yet by a few touches of his master hand every striking feature of the scene has been faithfully portrayed. We are told of 'the snowy Etna, the pillar of heaven—the nurse of everlasting frost, in whose deep caverns lie concealed the fountains of unapproachable fire—a stream of eddying smoke by day—a bright and ruddy flame

* Book iii., at the end.

by night; and burning rocks rolled down with loud uproar into the sea.'

Alessi, in his history of Etna, refers to Seneca, who, in the first century of our era, reminds Lucilius that Mount Etna had in his time lost so much of its height that it could be no longer seen by boatmen from certain points whence it had been previously visible. At a much later period, Falcando relates that the lofty summit of Etna had fallen in in 1179, and it was destroyed, according to Fazzello, for the third time in 1329. Again it was engulphed for the fourth time in 1444, and finally the whole top of the mountain fell in in 1669.* The result of these and previous truncations may well have produced the form of a truncated cone, represented in the accompanying drawing (fig. 85).

Eruption of 1669. *Monti Rossi formed.*—The great eruption last alluded to of 1669, deserves particular attention as the first noticed by scientific observers. An earthquake had levelled to the ground all the houses in Nicolosi, a town situated near the lower margin of the woody region, about 20 miles from the summit of Etna, and 10 from the sea at Catania. Two gulfs then opened near that town, from whence sand and scoriæ were thrown up in such quantity, that in the course of three or four months, a double cone was formed, called Monti Rossi (or Monte Rosso) about 450 feet high. But the most extraordinary phenomenon occurred at the commencement of the convulsion in the plain of S. Lio. A fissure six feet broad, and of unknown depth, opened with a loud crash, and ran in a somewhat tortuous course to within a mile of the summit of Etna. Its direction was from north to south, and its length 12 miles. It emitted a most vivid light. Five other parallel fissures of considerable length afterwards opened one after the other, and emitted vapour and gave out bellowing sounds which were heard at the distance of 40 miles. This case seems to present the geologist with an illustration of the manner in which those continuous dikes of vertical porphyry were formed, which are seen to traverse some of the older lavas of Etna; for the light emitted from the great rent of S. Lio

* Alessi, Storia critica dell' Eruz. dell' Etna, p. 149.

appears to indicate that the fissure was filled to a certain height with incandescent lava, probably to the height of an orifice not far from Monti Rossi, which at that time opened and poured out a lava current. When the melted matter in such a rent has cooled, it must become a solid wall or dike, intersecting the older rocks of which the mountain is composed; similar rents have been observed during subsequent eruptions, as in 1832, when they radiated in various directions from the centre of the volcano. It has been remarked by M. Elie de Beaumont, that such star-shaped fractures may indicate a slight upheaval of the whole of Etna. They may

Fig. 86.

Minor cones on the flanks of Etna.

1. Monti Rossi, near Nicolosi, formed in 1669. 2. Monpileri.

be the signs of the stretching of the mass, when it was being raised gradually by a force from below.*

The lava current of 1669, before alluded to, soon reached in its course a minor cone called Monpileri, at the base of which it entered a subterranean grotto, communicating with a suite of those caverns which are so common in the lavas of Etna. Here it appears to have melted down some of the vaulted foundations of the cone, so that the whole of that hill became slightly depressed and traversed by numerous open fissures.

Part of Catania destroyed.—The lava, after overflowing fourteen towns and villages, some having a population of

* Mém. pour servir, &c., tom. iv. p. 116.

between 3,000 and 4,000 inhabitants, arrived at length at the walls of Catania. These had been purposely raised to protect the city; but the burning flood accumulated till it rose to the top of the rampart, which was 60 feet in height, and then it fell in a fiery cascade and overwhelmed part of the city. The wall, however, was not thrown down, but was discovered long afterwards, by excavations made in the rock by the Prince of Biscari; so that the traveller may now see the solid lava curling over the top of the rampart as if still in the very act of falling.

This great current performed the first 13 miles of its course in 20 days, or at the rate of 162 feet per hour, but required 23 days for the last two miles, giving a velocity of only 22 feet per hour; and we learn from Dolomieu that the stream moved during part of its course at the rate of 1,500 feet an hour, and in others took several days to cover a few yards.* When it entered the sea it was still 600 yards broad, and 40 feet deep. It covered some territories in the environs of Catania, which had never before been visited by the lavas of Etna. While moving on, its surface was in general a mass of solid rock; and its mode of advancing, as is usual with lava streams, was by the occasional fissuring of the solid walls. A gentleman of Catania, named Pappalardo, desiring to secure the city from the approach of the threatening torrent, went out with a party of 50 men whom he had dressed in skins to protect them from the heat, and armed with iron crows and hooks. They broke open one of the solid walls which flanked the current near Belpasso, and immediately forth issued a rivulet of melted matter which took the direction of Paternó; but the inhabitants of that town, being alarmed for their safety, took up arms, and put a stop to further operations.†

As another illustration of the solidity of the walls of an advancing lava stream, I may mention an adventure related by Recupero, who, in 1766, had ascended a small hill formed of ancient volcanic matter, to behold the slow and gradual

* See Prof. J. D. Forbes, Phil. Trans. 1846, p. 155, on Velocity of Lava.
† Ferrara, Descriz. dell' Etna, p. 108.

approach of a fiery current, $2\frac{1}{2}$ miles broad; when suddenly two small threads of liquid matter issuing from a crevice detached themselves from the main stream, and ran rapidly towards the hill. He and his guide had just time to escape when they saw the hill, which was 50 feet in height, surrounded, and in a quarter of an hour melted down into the burning mass, so as to flow on with it.

But it must not be supposed that this complete fusion of rocky matter coming in contact with lava is of universal, or even common occurrence. It probably happens when fresh portions of incandescent matter come successively in contact with fusible materials. In many of the dikes which intersect the tuffs and lavas of Etna, there is scarcely any perceptible alteration effected by heat on the edges of the horizontal beds, in contact with the vertical and more crystalline mass. On the site of Monpileri, one of the towns overflowed in the great eruption above described, an excavation was made in 1704; and by immense labour the workmen reached, at the depth of 35 feet, the gate of the principal church, where there were three statues, held in high veneration. One of these, together with a bell, some money, and other articles, were extracted in a good state of preservation from beneath a great arch formed by the lava. It seems very extraordinary that any works of art, not encased with tuff, like those in Herculaneum, should have escaped fusion in hollow spaces left open in this lava current, which was so hot at Catania eight years after it had entered the town, that it was impossible to hold the hand in some of the crevices.

Subterranean caverns on Etna.—Mention was made of the entrance of a lava stream into a subterranean grotto, whereby the foundations of a hill were partly undermined. Such underground passages are among the most curious features on Etna, and may perhaps be caused by the sudden conversion into steam of lakes or streams of water overwhelmed by a fiery current. Great volumes of vapour thus produced may force their way through liquid lava already coated over externally with a solid crust, and may cause the sides of such passages as they harden to assume a very irregular outline. Near Nicolosi, not far from Monti Rossi, one of

those great openings may be seen, called the Fossa della Palomba, 625 feet in circumference at its mouth, and 78 deep. After reaching the bottom of this, we enter another dark cavity, and then others in succession, sometimes descending precipices by means of ladders. At length the vaults terminate in a great gallery 90 feet long, and from 15 to 50 broad, beyond which there is still a passage, never yet explored; so that the extent of these caverns remains unknown. The walls and roofs of these great vaults are composed of rough bristling scoriæ, of the most fantastic forms.

Changes produced by modern eruptions in the Val del Bove.— The change which had taken place in the aspect of several parts of Etna, but especially in the Val del Bove, between my first and second visits, or between 1825 and 1857, was very striking. That deep chasm is called in the provincial dialect of the peasants, 'Val di Bué,' for here the herdsman

——in reductâ valle *mugientium*
Prospectat errantes greges.

Dr. Buckland was, I believe, the first English geologist who examined this valley with attention, and I am indebted to him for having described it to me, before I visited Sicily, as more worthy of attention than any single spot in that island, or perhaps in Europe.

The views, Plates V. and VI. above described, p. 7, have already given the reader some idea of the scenery, looking up and down the vast amphitheatre, which is between 4 and 5 miles in diameter. The accompanying view, fig. 87, is part of a panoramic sketch, which I made from the summit of the highest cone on December 1, 1828. Every part of the mountain was then free from clouds, except the Val del Bove, some of the upper precipices of which, alone, were visible with their large vertical and projecting dikes as seen in the drawing. The crater nearest the foreground and the small cone adjoining were among those which had been thrown up during the eruptions of 1810 and 1811, or eighteen years before my visit.

The lavas which were poured out from near the head of the Val del Bove in those years, and subsequently in 1819,

flowed between some isolated rocks, called Finocchio, Capra, and Musara, which are remnants of the old cone of Etna, not destroyed at the time when the Val del Bove was formed. The position of these is pointed out at numbers 5, 6, and 9, in Plate V. Their height had already been much reduced by the flowing round them of the currents of 1811 and 1819, and in 1857 I found that the lavas of 1852 had still farther diminished their importance. When I first saw them as I

Fig. 87.

View from the summit of Etna into the Val del Bove.

ascended the valley, I compared them to the Trosachs in the Highlands of Scotland which

> Like giants stand
> To sentinel enchanted land;

though I remarked that the stern and severe grandeur of the scenery which they adorned, was not such as would be selected by a poet for a vale of 'enchantment.' The character of the scene would accord far better with Milton's picture of the infernal world; and if we imagine ourselves to behold in motion, in the darkness of the night, one of those fiery

currents which have so often traversed the great valley, we may well recall

> ——yon dreary plain, forlorn and wild,
> The seat of desolation, void of light,
> Save what the glimmering of these livid flames
> Casts pale and dreadful.

The strips of green herbage and forest land, which have here and there escaped the burning lavas, serve, by contrast, to heighten the desolation of the scene. When first I visited the valley, nine years after the eruption of 1819, I saw hundreds of trees, or rather the white skeletons of trees, on the borders of the black lava, the trunks and branches being

Fig. 88.

View of the rocks Finocchio, Capra, and Musara, Val del Bove.

all leafless, and deprived of their bark by the scorching heat emitted from the melted rock; an image recalling those beautiful lines:—

> As when heaven's fire
> Hath scath'd the forest oaks, or mountain pines,
> With singed top their stately growth, though bare,
> Stands on the blasted heath.

An unusual silence prevails throughout this region; for there are no torrents dashing from the rocks, nor any movement of running water in this valley, such as may almost invariably be heard in mountainous regions. Every drop of water that falls from the heavens, or flows from the melting

ice and snow, is instantly absorbed by the porous lava; and such is the dearth of springs, that the herdsman is compelled to supply his flocks, during the hot season, from stores of snow laid up in hollows of the mountain during winter.

Late in the autumn, when the sun is shining, both on the higher and lower parts of Etna, and on every other part of Sicily, clouds of fleecy vapour often fill the Val del Bove, and are sometimes partially dispersed along the face of the lofty precipices, causing the black outlines of the dikes to stand out in picturesque relief. About midday, when the vapours begin to rise, the changes of scene are varied in the highest degree, different rocks being unveiled and hidden by turns, and the summit of Etna often breaking through the clouds for a moment with its dazzling snows, and being then as suddenly withdrawn from the view.

Eruptions of 1811 *and* 1819.—I have alluded to the streams of lava which were poured forth in 1811 and 1819. Gemmellaro, who witnessed these eruptions, informs us that the great crater in 1811 first testified by its loud detonations that a column of lava had ascended to near the summit of the mountain. A violent shock was then felt, and a stream broke out from the side of the cone, at no great distance from its apex. Shortly after this had ceased to flow, a second stream burst forth at another opening, considerably below the first; then a third still lower, and so on till seven different issues had been thus successively formed, all lying upon the same straight line. It has been supposed that this line was a perpendicular rent in the internal framework of the mountain, which rent was probably not produced at one shock, but prolonged successively downwards, by the weight, pressure, and intense heat of the internal column of lava, as its surface subsided by gradual discharge through each vent.*

In 1819 three large mouths or caverns opened very near those which were formed in the eruptions of 1811, from which flames, red-hot cinders, and sand were thrown up with loud explosions. A few minutes afterwards another mouth opened below, from which flames and smoke issued; and

* Scrope on Volcanos, 1st ed. p. 160.

finally a fifth, lower still, whence a torrent of lava flowed, which spread itself with great velocity over the Val del Bove. When it arrived at the precipice called the Salto della Giumenta, at the head of the valley of Calanna, it poured over in a cascade, and made an inconceivable crash as it was dashed against the bottom. So immense was the column of dust it raised by the abrasion of the tufaceous hill over which the hardened mass descended, that the Catanians were in great alarm, supposing a new eruption to have burst out in the woody region, exceeding in violence that near the summit of Etna.

Mr. Scrope observed this current in the year 1819, slowly advancing down a considerable slope, at the rate of about a yard an hour, nine months after its emission. The lower stratum being arrested by the resistance of the ground, the upper or central part gradually protruded itself, and, being unsupported, fell down. This in its turn was covered by a mass of more liquid lava, which swelled over it from above. The current had all the appearance of a huge heap of rough and large cinders rolling over and over upon itself by the effect of an extremely slow propulsion from behind. The contraction of the crust as it solidified, and the friction of the scoriform cakes against one another, produced a crackling sound. Within the crevices a dull red heat might be seen by night, and vapour issuing in considerable quantity was visible by day.*

Eruption of August 1852.—Of all the recorded eruptions of Etna, with the exception of that of 1669 already mentioned, that which began in August 1852 and continued till May of the following year, was the most remarkable for the volume of lava which was poured out. In the annexed woodcut, fig. 89, I have given the outline of the two cones (marked 1852 in the Map, p. 10) from which in that year the lava issued, and in fig. 90 the course of the great stream is pointed out as it flowed from those cones *b*, *c*, through the Val del Bove, and beyond to Milo in one direction, or to the left, and to Zafarana on the right. Scoriæ were thrown up from the largest of the two cones *c*, which was formed together with *b*

* Scrope on Volcanos, 1st ed. p. 102.

at the base of the great precipice at the head of the Val del Bove. At the end of 16 days the cone *c* was about 500 feet high on its eastern side. So great was the expanse of molten matter that the whole valley when seen by Dr. Giuseppe Gemmellaro at the end of August was like a sea of fire. In September it reached the Salto della Giumenta before mentioned. In its descent over the precipice it sounded as if metallic and glassy substances were being broken. The lava streams *d d'*, which poured out till the latter part of November, were about 2 miles broad and 6 long. They continued to issue with some intermissions for more than nine months until May 1853. The depth of single streams was from 8 to 16 feet, but when

Fig. 89.

The two cones formed in the Val del Bove by the eruption of 1852.

A. Lower part of Giannicola Grande.
b. Upper or western cone.
c. Lower cone, called Centenario.
d. Commencement of current of lava of 1852.

piled over one another they were from 30 to 50 feet thick, and at one point near the Portella or lower entrance of the valley of Calanna they seemed to me to have attained a thickness of 150 feet.

An unusual event, and one of no small geological interest, occurred some weeks after May 27th, when to all appearance the flowing of lava had entirely ceased, and when all the currents had become encrusted over with so firm a covering of scoriæ that the inhabitants could walk upon them with safety. Within a certain area six or seven hundred yards in diameter, and situated between Zafarana and Ballo, all the fruit trees and vines were struck dead as if by lightning. The ground exhaled no hot gases, and the vegetation did not suffer in the space intervening between the parched-up area and the recent lava, which was only a few hundred yards distant. Dr. Giuseppe Gemmellaro has suggested, as the most natural explanation of the phenomenon, that the lava had gradually made its way through underground pas-

sages, until coming beneath the fields alluded to, it dried up the roots of the plants by its heat. It is well known (see above, p. 24) that vaults and tunnels abound in many of the modern lavas of Etna, and such empty spaces must sometimes at subsequent periods unavoidably become filled with fused matter, which may then solidify under considerable pressure, giving rise to masses of crystalline rock or sometimes perhaps to tortuous veins like those represented in fig. 84, p. 17, and offering a perplexing problem to a geologist who might obtain a section of them without having any clue to the peculiar conditions under which they originated.*

Fig. 90.

Course of the lava currents through the Val del Bove in 1852–3, as seen from above.

a. Part of Giannicola Grande.
b, c, d. Same as fig. 89.
e. Monte Finocchio Inferiore.
f. Rocca Musara.
g. Giannicola Piccola.
h, h. Concazze.
i, i. Serra del Solfizio.

In 1858 I found the surface of this lava of 1853 still giving out columns of white steam from numerous fumeroles, especially after heavy rains. Near Zafarana its surface is divided into longitudinal ridges rising from 30 to 70 feet above the bottom of the intervening and parallel depressions.

It was a melancholy sight to behold pastures which I had seen verdant in 1828 in the valley of Calanna black and desolate, and the region above so deluged with the sterilising products of the late eruption that there had ceased to be a picturesque contrast between tracts of the old forest and dark strips of modern lava. The larger part of the great valley had become one monotonous desert no longer supporting any cattle, nothing to justify its original name, and with scarcely a living creature to be seen, though a few goats were

* Etna Paper, p. 22; see above, p. 9.

still driven up to browse on some shrubby knolls which had escaped the general devastation. After passing several days without seeing even a goat, the foot marks of a wolf imprinted at one point on some loose volcanic sand quite surprised me and made me enquire where they could still find any prey.

I crossed on foot a part of the new lava-field, in company with Signor G. G. Gemmellaro, to the rock called Finocchio, which in 1828 I had reached easily on mule-back. There was now no foot-path leading to it, and we found the black scoriaceous crust of the lava of 1852 bent into exceedingly sharp, longitudinal ridges, separated by narrow interspaces from 20 to 40 feet deep, the sides of each ridge sloping at angles of from 20° to 40°, but seeming at some points to be absolutely vertical. On the crests of each ridge were fragments of scoriform lava, sometimes tabular, and sticking up edgeways, like sheets of broken ice on a Canadian river, where an obstruction or 'jam' has stopped the floating masses. More frequently the projecting portions of the superficial crust assumed the forms of gigantic madrepores, or of various animals, such as dogs and deer, or still oftener the heads of elks with branching horns. The surface often resembled, in all but colour, the descriptions given of coral reefs; and at one moment when my foot slipped, I had an opportunity of knowing that the stony asperities could tear the flesh of my hands as readily as real corals. The stones on the top and sides of most of the ridges were so loose, that no sooner was one of them set a-rolling than it started a number of others, until a continuous avalanche poured down into the trough below; but as we had to zigzag our way up each steep ascent, there was little danger of one of us being just under his companion when the torrent came down. Now and then our direct march was arrested by a ridge, rendered impassable by its steepness or the incoherence of the stony fragments forming its crust, which obliged us to make a long circuit, often with our backs turned towards our goal, the hill of Finocchio. The manner in which detached blocks of various shapes and sizes were occasionally poised one upon another, on very narrow ridges, made us marvel that high winds had not blown them down. I climbed up to some of

them, to ascertain that they were not soldered on to the mass of scoriæ below; but I found them free to move and only holding on by the slight inequalities of their surface.

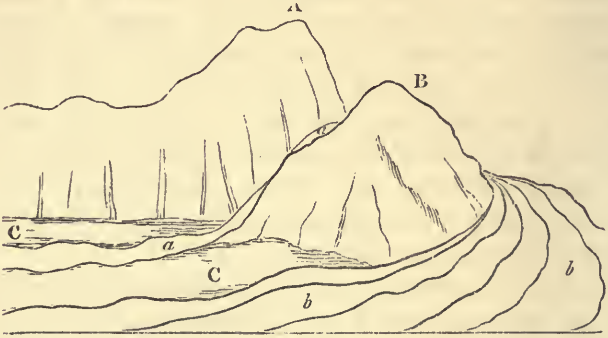
When at length we reached Finocchio we found it standing like a rocky islet submerged up to its middle in lavas of different ages, and with the fresh current of 1852 near its base. The relief afforded to the eye by that oasis was very great; and although the day was cloudy, the green turf enlivened by the flowers of a yellow ragwort, looked dazzling by contrast with the dark surrounding desert, and the autumnal crocus (*colchicum autumnale*), also in full bloom, seemed more than ever beautiful.

The manner in which pieces of loose scoriæ had often rolled down in great numbers from the ridges into the troughs of the lava serves to show to what an extent superficial inequalities may be reduced, or even effaced, when fresh currents overflow older ones. This may partly account for the regularity and parallelism of the successive stony lavas with their upper and under scoriæ in the escarpments of the Val del Bove; but the chief reason why those ancient currents are for the most part so conformable to each other is, I believe, the steepness of the slope down which they descended; the lofty and sharp ridges above described being characteristic of lavas flowing on more level ground or down slightly inclined planes. When they descend very steep slopes the very moderate thickness which they attain is alone sufficient to preclude the possible formation of undulations like those just described, which are from 10 to 30 feet or more in height.

Cascades of lava at Salto della Giumenta.—Some very instructive examples are to be seen at various points on Mount Etna of the external form and internal structure assumed by currents of lava of known date which have flowed down very steep slopes. To one of these, which was precipitated in 1819 down a precipice which forms the head of the valley of Calanna, allusion has already been made, page 29. This precipice, called the Salto della Giumenta, is about 400 feet high and several hundred wide. In the annexed drawing, fig. 91, which I made in 1828, it is seen in profile, with a branch of the lava of 1819 *a*, flowing over it. Fig. 92 is a front

view of the same, which I sketched in 1858, when a much more copious stream of melted matter (part of the current of 1852)

Fig. 91.



Modern lavas, as they appeared in 1828, descending the precipice called the Salto, at the head of the valley of Calanna, and flowing round the hill of that name.

A. Zoccolaro.

B. Monte di Calanna.

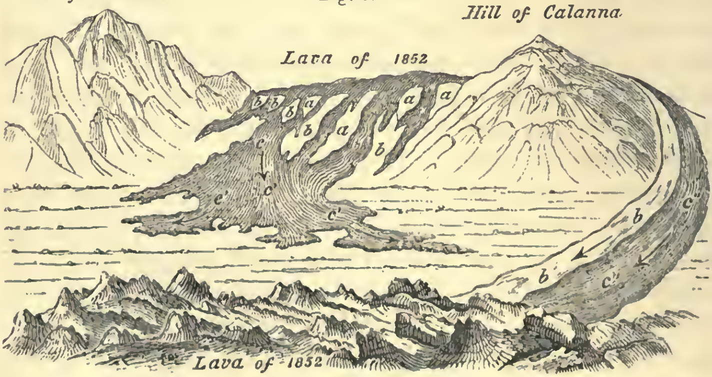
C. Plain at the head of the Valley of Calanna.

a. Lava of 1819 descending the precipice called Salto della Giumenta, and flowing through the valley.

b. Lavas of 1811 and 1819 flowing round the hill of Calanna.

had cascaded down the same height and overflowed the plain below. The greater part, however, of the same current *c*, like

Fig. 92.



Lava of 1852 cascading down the precipice called Salto della Giumenta.

a, a. Portions of the face of the precipice composed of rocks like those of Zoccolaro and Calanna, which have not been concealed by the modern lavas.

b. Lava of 1819 which flowed down and encrusted the face of the precipice.

b— → *b*. Same lava passing round the promontory of Calanna, together with the lava of 1811 which had followed the same course.

c. Lava of 1852 which cascaded over the precipice.

c′. The same lava overflowing the level plain of the valley of Calanna.

c″. Same lava flowing round the promontory and covering parts of the older currents of 1811 and 1819.

its predecessors of 1811 and 1819, turned round the promontory formed by the hill of Calanna, and moving right onwards has been piled up on the left side of the valley of Calanna so as to heighten its boundary wall without flowing down into it.

Both the lavas of 1819 and 1852 had been covered originally in every part where they congealed on the face of the steep precipice with the usual scoriaceous crust. But this crust, about three feet thick, has been washed off by rain at several places, and had exposed to view a solid and continuous stony layer below. The rock is somewhat vesicular, and contains crystals of felspar, augite, and olivine, with some titaniferous iron. As it is inclined at angles of from 35° to 50°, it affords a striking refutation of the doctrine that stony layers can only consolidate on slopes of from 3° to 5°.

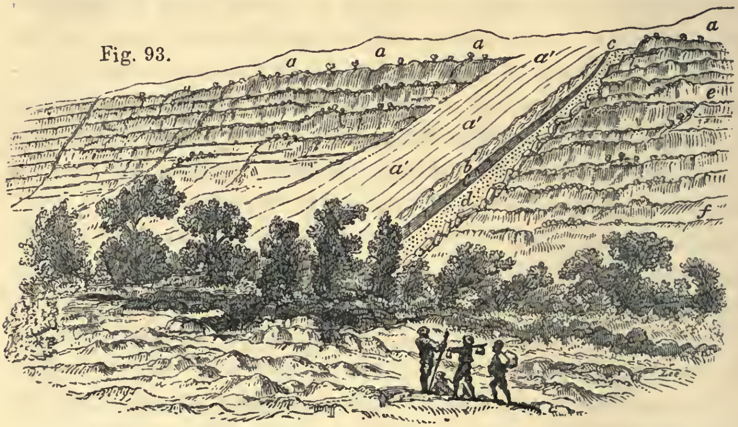
Inclined lava of Cava Grande.—Among other examples attesting the erroneousness of the notion just alluded to, I may call attention to another cascade of lava the internal structure of which is still more clearly exposed to view. On the eastern flank of Etna, north of Milo, is a deep and narrow gully called the Cava Grande (see Map, fig. 77, p. 10), which, although usually dry, has been entirely excavated through successive beds of ancient lava and scoriæ by the waters of occasional floods, which cascade over a perpendicular precipice of a horseshoe form, at the upper end of the ravine. The torrent is gradually cutting its way backwards, and thus adding to the length of the narrow valley. I witnessed, October 1857, several avalanches of sand and stones loosened from the terminal cliff by the heavy rains of the preceding day. The boundary walls of the opposite sides of the Cava Grande are 220 feet high, in part vertical, in part sloping at angles of between 38° and 65°.

In the year 1689, a lava stream descended from the Val del Bove in a direction nearly parallel to the Cava Grande, but a portion of its left side was precipitated into the ravine in the manner represented at a' a' a' in figure 93.

In addition to the retrogressive excavation of the head of the ravine caused by the torrent before mentioned, the steep boundary precipices are also undergoing constant waste, by which means a clear vertical section of the interior structure

of the current a' a is exposed to view as shown in the diagrams, figs. 93 and 94. It is evident that when the lava

Fig. 93.



Highly inclined lava of Cava Grande. From a sketch made October 1857.

a, a. Main stream of lava of 1689 flowing eastward.

a′, a′. Branch of the same lava cascading northwards into the ravine called the Cava Grande, with a mean inclination of 35°.

b. Section of upper or scoriaceous part of the current, 6 feet thick.

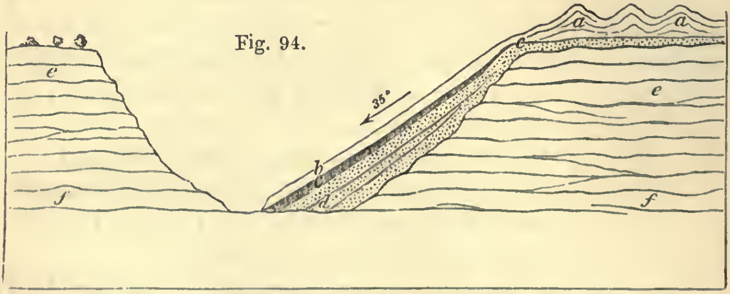
c, c. Solid layer of stony lava from 2½ to 5 feet thick, inclined at an angle of 35° and at its upper extremity at 47°.

d. Scoriaceous beds forming the base of the stream *a′, a′*, and underlying the stony layer *c.*

e, f. Cliff containing 10 ancient lava currents of Etna, appearing horizontal, but being in fact inclined at 7° to the east, or towards the sea.

reached the edge of the precipice, fragments of the solid crust with much loose scoriæ first rolled down, producing a talus by which the general slope of the cliff was reduced to

Fig. 94.



Supposed north and south section of the rocks at the Cava Grande near the head of the ravine.

a. Lava of 1689 with lofty parallel east and west ridges.

b, c, d, e, f. Same as in fig. 93.

an angle of between 30° and 35°. Near the top, however, at *c*, part of the lava consolidated at an angle of 47°, the stony layer *c* being there only $2\frac{1}{2}$ feet thick, whereas it has twice that thickness where it is less inclined (viz. at 35°) below. The rock formed on this steep slope is as compact as our ordinary ancient trap-rocks, and has the same specific gravity as commonly belongs to them. It contains crystals of felspar, and a small quantity of olivine. It is divided by a few joints at right angles to the cooling surfaces.

Flood of 1755 *in the Val del Bove.*—Before I allude to the action of running water in excavating ravines on the flanks of Etna, it may be well to mention the only instance on record of a great body of water having passed from the higher region of the mountain through the Val del Bove. This occurred in the year 1755. An eruption had taken place at the summit of the volcano, in the month of March, a season when the top of the mountain was covered with snow. The Canon Recupero, a good observer, and a man of great sagacity, was commissioned by Charles of Bourbon, king of Naples, to report on the nature and cause of the catastrophe. He accordingly visited the Val del Bove in the month of June, three months after the event, and found that the channel of the recent flood, nearly two miles broad, was still strewed over with sand and fragments of rock to the depth of 34 feet.

The volume of water in a length of one mile he estimated at 16,000,000 cubic feet, and he says that it ran at the rate of a mile in a minute and a half for the first twelve miles. At the upper end of the Val del Bove, all the pre-existing inequalities of the ground, for a space of two miles in length, and one in breadth, were perfectly levelled up and made quite even, and the marks of the passage of the flood were traceable from thence up the great precipice (or Balzo di Trifoglietto), to the Piano del Lago, or highest platform. Recupero, in his report, maintains that if all the snow on Etna, which he affirms is never more than four feet deep (some chasms we presume excepted), were melted in one instant, which no current of lava could accomplish, it would not have supplied such a volume of water. He came therefore

to the somewhat startling conclusion, that the water was vomited forth by the crater itself, and was driven out from some reservoir in the interior of the mountain.*

It seems to me very unlikely that the Canon, who was on the ground within three months of the date of the catastrophe, could have been mistaken in regard to the region whence the waters came. His conclusions on that head seem to have been legitimately deduced from the fact that the wreck of the inundation was traceable continuously from the sea-shore at Riposto up to the highest cone or its immediate neighbourhood. I am, therefore, inclined to suspect that at the time of the eruption of 1755 there was upon the summit of Etna, not only the winter's snow of that year, but many older layers of ice alternating with volcanic sand and lava, at the foot or in the flanks of the cone, which were suddenly melted by the permeation through them of hot vapours, and the injection into them of melted matter.

Glacier preserved by a covering of lava.—I stated in 1828,† that I ascertained the fact of the existence of a glacier under lava near the Casa Inglese, on the S.E. side of the highest cone, and that it had been quarried during the previous summer, affording a supply of ice to the Catanians, at the close of an unusually hot season. On returning thirty years afterwards (September 1858), I found the same mass of ice, of unknown extent and thickness, still unmelted. It had been quarried only five years before, to the depth of four feet, on the very same spot. My guide told me that he had seen this mass of solid ice, the bottom of which they did not reach, and that it was overlaid by ten feet of sand, and the sand again by lava.

Signor Mario Gemmellaro had satisfied himself in 1828 that nothing but the subsequent flowing of the lava over the snow could account for the position of the glacier. We may suppose that, at the commencement of the eruption, a deep mass of drift snow had been covered by volcanic sand showered down upon it before the descent of the lava. A dense stratum of this fine dust mixed with scoriæ is well

* Recupero, Storia dell' Etna, p. 85.

† Principles of Geology, 1st edition, p. 369.

known to be an extremely bad conductor of heat; and the shepherds in the higher regions of Etna are accustomed to provide water for their flocks during summer, by strewing a layer of volcanic sand a few inches thick over the snow, which effectually prevents the heat of the sun from penetrating.

Suppose the mass of snow to have been preserved from liquefaction until the lower part of the lava had consolidated, we may then readily conceive that a glacier thus protected, at the height of 10,000 feet above the level of the sea, would endure as long as the snows of Mont Blanc, unless melted by volcanic heat from below. When I first visited the summit of the highest cone in the beginning of winter (December 1st, 1828), I found the crevices in the interior encrusted with thick ice, and in some cases hot vapours were actually streaming out between masses of ice and the rugged and steep walls of the crater. Paradoxical, therefore, as it may appear, we cannot doubt that a great mass of ice was preserved from melting, by the singular accident of a current of lava flowing over it.

If, then, glaciers may endure for a series of years under volcanic sand and lava, the store of water which Recupero speculated upon as contained somewhere in the interior of the mountain, seems sufficiently accounted for. I am also now disposed to attach more importance than when I first wrote on this subject, to the tales of the mountaineers, which Recupero thought worth recording. They related to him that the water was boiling, that it was as salt as the sea, and that it brought down with it sea-shells to the coast. Now it will be seen that the hypothesis above suggested would very naturally account for the water being hot, and it may have been impregnated with saline matter exhaled from fumeroles on the sides of the cone or from the crater itself during the eruption, and these exhalations, without giving to it the composition of sea-water, may have taken away its freshness. As to the story of the marine shells, if the flood, after issuing from the Val del Bove, cut deeply through the superficial lava or the alluvium between Milo and Giarre, it may have reached some of the beds of the subjacent Newer Pliocene

clay, at the height of 1,000 or 1,200 feet above the sea, washing out of it fossil shells of living species strong enough to bear transportation as far as Riposto.

Ancient valleys of Etna.—The action of volcanos is, as we have already seen, characteristically intermittent even when they are in a phase of frequent eruption; but we have good reason to believe that if their history could be known for thousands of years, we should find that there are very long periods, during which they lie dormant, and then have their fires resuscitated. From Junghuhn's account of the numerous cones of Java, it appears that these volcanos are subject to protracted periods of inaction, during which valleys, deepening as they descend, are eroded by running water on all their sides; at length a paroxysmal outburst occurs, by which part of the cone is destroyed, and then lavas again pour out from time to time. Mr. Dana, in his account of the great cones of the Sandwich Islands, states that the comparative length of the periods during which any one of them has been at rest may be estimated by the depth and size of the valleys which furrow their sides; but the time which such denudation may have occupied has often been so vast that we cannot attempt, with our present knowledge, to form any conjecture as to its duration.

From what was said of Vesuvius in the last chapter, the reader is aware that until the year 79 of our era, it had all the characters of an extinct volcano. The only part of the exterior of the ancient cone which still retains that physiognomy by which the whole of it must have been characterised before the renewal of its volcanic activity, is the northern side, scarcely ever visited by travellers, and which we have described as being intersected by numerous deep ravines, radiating as from a central axis towards all points of the compass. On ascending several of these ravines, we have seen that they terminate abruptly in perpendicular precipices from 60 to 300 feet in height, where in the rainy season there are waterfalls.* Above the head of such precipices shallow valleys continue upwards to the crest of the boundary wall of the Atrio del Cavallo, and no doubt were once con-

* See Vol. I. p. 635.

tinued to near the summit of the old cone of Somma, before that mountain was truncated in the year 79.

In like manner I conceive that, long before the historical era, Mount Etna may have been furrowed on all sides by valleys during a long interval of comparative rest, or, perhaps, a total suspension of eruptions.

The vast deposits of alluvial matter, more than 100 feet thick, which are seen along the coast eastward of the Val del Bove, between Giarre and Maugano, and which may sometimes be traced up to the height of 400 feet, attest the enormous amount of erosion which the eastern flanks of Etna have undergone at a remote period.

At length one or more paroxysmal outbreaks, to which the Val del Bove may have owed its origin, ushered in a period of renewed activity to which the lateral cones are principally due. The lavas pouring out successively on the northern, western, and southern flanks obliterated all the ancient valleys on those three sides, and would have done the same on the eastern flank of the cone had they not been intercepted in their course by that huge chasm, the Val del Bove, which they have already, in great part, filled up. Three valleys or ravines, which have escaped obliteration, deserve notice as bearing the same relation to the margin of the Val del Bove which the valleys on the north of Vesuvius (those of the Casa dell' Acqua and others, described at page 635, Vol. I.) bear to the Atrio del Cavallo. These three valleys on the south-east side of Etna are the Valle del Tripodo, the Valle dei Zappini, and the Valle di Calanna, the position of which will be seen in the Map, fig. 77, p. 10. The first of them, the Valle del Tripodo, although not difficult of access from Zafarana, is scarcely ever visited by travellers. It is a beautiful, wooded, Alpine ravine down which a torrent flows. On reaching the head of this ravine, or the col which divides it from the Val del Bove, a truly splendid view is obtained of all the grand features of that vast amphitheatre before described. Although the col is no less than 7,000 feet high above the level of the sea, it forms the lowest part of a deep notch in the southern escarpment of the Val del Bove or the Sierra del Solfizio. (See Map, fig. 77.) The depth of the

gap must be great, as it enables an observer, looking at Etna from a vessel at sea off Aci Castello, to get a view of the Val del Bove through the opening. This notch is a section of a ravine of denudation once continuous with the Valle del Tripodo, which furrowed the old cone before the Val del Bove was formed.

The second valley, called 'dei Zappini,' runs parallel to the former, and is similar in its geological features, though less grand. The torrents that drain both of them are swallowed up at their lower end in the holes and grottoes of the great lava current of 1792, which, flowing down from a different and higher part of Etna, crossed the channels of these torrents and blocked up the ravines in which they flow.

The third valley, that of Calanna before alluded to, is the most interesting, because at its upper end we find the precipice before described, figs. 91 and 92, p. 34, over which the modern lavas of 1819 and 1852 have cascaded. There can be no doubt that this precipice, the Salto della Giumenta, was the site of a waterfall when a river flowed down from the ancient cone, before the origin of the Val del Bove. The space between the hills of Zoccolaro and Calanna indicates the place of the upper valley, while the Salto was formed by the river cutting its way backwards after the manner of the stream in the Cava Grande before described, p. 35, or of the retrograding torrents of Vesuvius, or, to compare small things with great, the river Niagara at its falls.

If Vesuvius continues to be as active as it has been for the last eighteen centuries, its lavas may one day top the crest of the Atrio and cascade over the precipices at the head of the Casa dell' Acqua and the Fosso di Cancharoni, in the same way as the Etnean streams of 1819 and 1852 have cascaded down the Salto della Giumenta.

Antiquity of the cone of Etna.—It was before remarked (Vol. I., p. 89) that confined notions in regard to the quantity of past time have tended, more than any other prepossessions, to retard the progress of sound theoretical views in geology; the inadequacy of our conceptions of the earth's antiquity having cramped the freedom of our speculations in this science, very much in the same way as a belief in the exist-

ence of a vaulted firmament once retarded the progress of astronomy. It was not until Descartes assumed the indefinite extent of the celestial spaces, and removed the supposed boundaries of the universe, that just opinions began to be entertained of the relative distances of the heavenly bodies; and until we habituate ourselves to contemplate the possibility of an indefinite lapse of ages having been comprised within each of the modern periods of the earth's history, we shall be in danger of forming most erroneous and partial views in geology.

If history had bequeathed to us a faithful record of the eruptions of Etna, and 100 other of the principal active volcanos of the globe, during the last 3,000 years,—if we had an exact account of the volume of lava and matter ejected during that period, and the times of their production,—we might, perhaps, be able to form a correct estimate of the average rate of the growth of a volcanic cone. For we might thus obtain a mean result by the comparison of the eruptions of so great a number of vents, however irregular might be the development of the igneous action in any one of them, if contemplated singly during a brief period.

It would be necessary to balance protracted periods of inaction against the occasional outburst of paroxysmal explosions. Sometimes we should have evidence of a repose of sixteen centuries, like that which was interposed in Ischia, between the end of the fourth century B.C. and the beginning of the fourteenth century of our era.* Occasionally a tremendous eruption like that of Jorullo or that of Papandayang and others alluded to at page 11, would be recorded, giving rise at once to a new mountain, or to the truncation of an ancient cone, or to some vast lateral cavity like the Val del Bove. But the comparative rarity of such catastrophes exalts our conception of the great duration of the intervals of rest which occur between eras of paroxysmal violence.

If we desire to approximate to the age of Etna, we ought first to obtain some data in regard to the thickness of matter which has been added during the historical era, and then endeavour to estimate the time required for the accumulation

* See Vol. I. p. 606.

of such alternating lavas and beds of sand and scoriæ as are superimposed upon each other in the Val del Bove; afterwards we should try to deduce, from observations on other volcanos, the more or less rapid increase of burning mountains in all the different stages of their growth.

Although it is possible that some of the ancient eruptions of which the products are seen in the walls of the Val del Bove were on as grand a scale as those of our own time or even grander, yet we should in vain seek for evidence that any one of those ancient currents equalled in volume the lavas of 1669 or those of 1852.

There is a considerable analogy between the mode of increase of a volcanic cone and that of trees of *exogenous* growth. These trees augment, both in height and diameter, by the successive application externally of cone upon cone of new ligneous matter; so that if we make a transverse section near the base of the trunk, we intersect a much greater number of layers than nearer to the summit. When branches occasionally shoot out from the trunk, they first pierce the bark, and then, after growing to a certain size, if they chance to be broken off, they may become inclosed in the body of the tree, as it augments in size, forming knots in the wood, which are themselves composed of layers of ligneous matter, cone within cone.

In like manner, a volcanic mountain consists, as we have seen, of a succession of conical masses enveloping others, while lateral cones, having a similar internal structure, often project in the first instance, like branches from the surface of the main cone, and then becoming buried again, are hidden like the knots of a tree.

We can ascertain the age of an oak or pine by counting the number of concentric rings of annual growth seen in a transverse section near the base, so that we may know the date at which the seedling began to vegetate. The Baobab-tree of Senegal (*Adansonia digitata*) is supposed to exceed almost any other in longevity. Adanson inferred that one which he measured, and found to be thirty feet in diameter, had attained the age of 5,150 years. Having made an incision to a certain depth, he first counted 300 rings

of annual growth, and observed what thickness the tree had gained in that period. The average rate of growth of younger trees, of the same species, was then ascertained, and the calculation made according to a supposed mean rate of increase. De Candolle considers it not improbable that the celebrated Taxodium of Chapultepec, in Mexico (*Cupressus disticha*, Linn.), which is 117 feet in circumference, may be more aged.

It is, however, impossible, until more data are collected respecting the average intensity of the volcanic action, to make anything like an approximation to the age of a cone like Etna; because, in this case, each successive envelope of lava and scoriæ is not of simultaneous growth round the mountain, like the layers of wood round a tree, and therefore affords us no corresponding and definite measure of time. Each conical envelope is made up of a great number of distinct lava currents and showers of sand and scoriæ differing in width and depth, and also the results of intermittent action exceedingly variable as to intensity and frequency of recurrence. Yet we cannot fail to form the most exalted conception of the antiquity of this mountain, when we consider that its base is about 90 miles in circumference; so that it would require 90 flows of lava, each a mile in breadth at its termination, to raise the present foot of the volcano as much as the average height of one lava current.

The injection of several thousand dikes into the mass of matter previously accumulated, is more comparable, as M. E. de Beaumont has hinted, to the endogenous growth of a tree, implying the stretching outwards and perhaps upwards also of the mountain. But observations within the historical era are too imperfect to enable us to decide whether the mountain has gained or lost in altitude at those periods when new fissures have been formed and filled.

Of the 80 most conspicuous minor cones which adorn the flanks of Etna, only one of the largest, Monti Rossi, has been produced within the times of authentic history. Even this hill, thrown up in the year 1669, although 450 feet in height, only ranks as a cone of second magnitude. Monte Minardo, near Bronte, rises, even now, to the height of 750 feet,

although its original base has been elevated by more modern lavas and ejections. It must also be remembered, that of the small number of lava streams which are poured forth in a century, one only is estimated to issue from the summit of Etna for every two that proceed from the sides. Nor do all the lateral eruptions give rise to such hills as would be reckoned amongst the 200 lateral cones before alluded to, p. 2, as laid down in Waltershausen's map. Some of them produce merely insignificant monticules, which are soon after overwhelmed by showers of ashes proceeding from higher vents.

How many years, then, must we not suppose to have been expended in the formation of all the minor cones? If we could strip off from Etna the whole of those now visible, together with the lavas and scoriæ that have been poured out from them, and from the highest crater, during the period of their growth, the diminution of the entire mass would be extremely slight; Etna might lose, perhaps, several miles in diameter at its base, but the aspect of the woody region would not be essentially changed, because other minor cones, now concealed, would be recalled as it were into existence by the removal of the lava and ejected matter under which they now lie buried. As to the height of the mountain during the early stages of the phase of lateral eruptions, it may have been much greater before its summit was truncated than it is now, even if we make allowance for a slight accession of height due to the gradual upheaval of the whole mass above the level of the sea, as testified by the raised beaches on the coast before described.

To attempt to estimate the number of centuries which have elapsed since the first submarine eruptions began would be idle, because there may have been periods of tranquillity such as that in which the ancient valleys were excavated, enduring perhaps for tens of thousands of years, and then followed by paroxysmal outbursts like that to which the Val del Bove may have owed its origin.

No general deluge can have occurred in the forest zone of Etna since the lateral cones were thrown up. For few, if any, of these heaps of loose scoriæ could fail to have been

swept away by a great flood, and any remaining would have exhibited some signs of its denuding action. To some, perhaps, it may appear that hills of such incoherent materials cannot be of very great antiquity, because the mere action of the atmosphere must, in the course of several thousand years, have obliterated their original forms. But there is no weight in this objection; for although the steep slopes of Monti Rossi, being still bare and composed in great part of light scoriæ and fine volcanic sand, have been acted upon both by wind and rain within the memory of persons now living, yet the older hills have been protected from waste ever since they have been covered with trees and herbage. Even before dense vegetation has been established, such is the porosity of their component materials, that almost all the rain which falls upon them is instantly absorbed; and for the same reason that the rivers on Etna have subterranean courses, there are no rills descending the sides of the minor cones.

In conclusion, I may remind the reader that, however vast may be the lapse of ages which we require for the growth of a mountain like Etna, there has been ample time for its passage through every phase of its development. Its foundations were laid in the sea, in the Newer Pliocene period—that sea in which the shells of Aci Castello and Trezza flourished. We have seen, at p. 6, that the events of the Glacial period, though they may have occupied several hundred thousand years, do not reach back to an era when the assemblage of marine testacea differed as much as those of Aci Castello and Trezza differ from the fauna now characterising the neighbouring parts of the Mediterranean.

CHAPTER XXVII.

VOLCANIC ERUPTIONS—*concluded.*

VOLCANIC ERUPTION IN ICELAND IN 1783—NEW ISLAND THROWN UP—LAVA CURRENTS OF SKAPTÁR JOKUL, IN SAME YEAR—THEIR IMMENSE VOLUME—ERUPTION OF JORULLO IN MEXICO—HUMBOLDT'S THEORY OF THE CONVEXITY OF THE PLAIN OF MALPAIS—ERUPTION OF GALONGOON IN JAVA—SUBMARINE VOLCANOS—GRAHAM ISLAND, FORMED IN 1831—VOLCANIC ARCHIPELAGOS—SUBMARINE ERUPTIONS IN MID-ATLANTIC—THE CANARIES—CONES THROWN UP IN LANCEROTE, 1730–36—SANTORIN AND ITS VOLCANIC ERUPTIONS—BARREN ISLAND IN THE BAY OF BENGAL—MUD VOLCANOS—MINERAL COMPOSITION OF VOLCANIC PRODUCTS.

Volcanic eruptions in Iceland.—With the exception of Etna and Vesuvius, the most complete chronological records of a series of eruptions are those of Iceland, for their history reaches as far back as the ninth century of our era; and from the beginning of the twelfth century, there is clear evidence that, during the whole period, there has never been an interval of more than forty, and very rarely one of twenty years, without either an eruption or a great earthquake. So intense is the energy of the volcanic action in this region, that some eruptions of Hecla have lasted six years without ceasing. Earthquakes have often shaken the whole island at once, causing great changes in the interior, such as the sinking down of hills, the rending of mountains, the desertion by rivers of their channels, and the appearance of new lakes.* New islands have often been thrown up near the coast, some of which still exist; while others have disappeared, either by subsidences or the action of the waves.

In the interval between eruptions, innumerable hot springs afford vent to the subterranean heat, and solfataras discharge copious streams of inflammable matter. The volcanos in different parts of this island are observed, like those of the

* Von Hoff, vol. ii. p. 393.

Phlegræan Fields, to be in activity by turns, one vent often serving for a time as a safety-valve to the rest. Many cones are often thrown up in one eruption, and in this case they take a linear direction, running generally from north-east to south-west from the north-eastern part of the island, where the volcano Krabla lies, to the promontory Reykianas.

Great eruption of Skaptár Jokul in 1783.—*New island thrown up.*—The convulsions of the year 1783 appear to have been more tremendous than any recorded in the modern annals of Iceland; and the original Danish narrative of the catastrophe, drawn up in great detail, has since been substantiated by several English travellers, particularly in regard to the prodigious extent of country laid waste, and the volume of lava produced.* About a month previous to the eruption of Skaptár Jokul on the mainland, presently to be mentioned, a submarine volcano burst forth in the sea in lat. 63° 25′ N., long. 23° 44′ W., at a distance of 30 miles in a south-west direction from Cape Reykianas, and ejected so much pumice that the ocean was covered with that substance to the distance of 150 miles, and ships were considerably impeded in their course. A new island was formed, from which fire, smoke, and pumice were emitted at different points. This island was claimed by his Danish Majesty, who denominated it Nyöe, or the New Island; but before a year had elapsed the sea resumed its ancient domain, and nothing was left but a reef of rocks from 5 to 30 fathoms under water.

Earthquakes which had long been felt in Iceland, became violent on June 11, 1783, when Skaptár Jokul, distant nearly 200 miles from Nyöe, threw out a torrent of lava which flowed down into the Skaptâ, and completely dried it up. The channel of the river was between high rocks, in many places from 400 to 600 feet in depth, and near 200 in breadth.

* The first narrative of the eruption was drawn up by Stephenson, then Chief Justice in Iceland, appointed commissioner by the King of Denmark for estimating the damage done to the country, that relief might be afforded to the sufferers. Henderson was enabled to correct some of the measurements given by Stephenson, of the depth, width, and length of the lava currents, by reference to the MS. of Mr. Paulson, who visited the tract in 1794, and examined the lava with attention. (Journal of a Residence in Iceland, &c., p. 229.) Some of the principal facts are also corroborated by Sir William Hooker, in his 'Tour in Iceland,' vol. ii. p. 128.

Not only did the lava fill up this great defile to the brink, but it overflowed the adjacent fields to a considerable extent. The burning flood, on issuing from the confined rocky gorge, was then arrested for some time by a deep lake, which formerly existed in the course of the river, between Skaptardal and Aa, which it entirely filled. The current then advanced again, and reaching some ancient lava full of subterraneous caverns, some of them apparently filled with water, melted parts of the rock and blew up others, throwing large fragments to the height of 150 feet into the air. On June 18, another ejection of liquid lava rushed from the volcano, which flowed down with amazing velocity over the surface of the first stream. By the damming up of the mouths of some of the tributaries of the Skaptâ, many villages were completely overflowed with water, and thus great destruction of property was caused. The lava, after flowing for several days, was precipitated down a tremendous cataract called Stapafoss, where it filled a profound abyss, which that great waterfall had been hollowing out for ages, and after this, the fiery current again continued its course.

On August 3, fresh floods of lava still pouring from the volcano, a new branch was sent off in a different direction; for the channel of the Skaptâ was now so entirely choked up, and every opening to the west and north was so obstructed, that the melted matter was forced to take a new course, so that it ran in a south-east direction, and discharged itself into the bed of the river Hverfisfliot, where a scene of destruction scarcely inferior to the former was occasioned. These Icelandic lavas (like the ancient streams which are met with in Auvergne, and other provinces of Central France) are stated by Stephenson to have accumulated to a prodigious depth in narrow rocky gorges; but when they came to wide alluvial plains, they spread themselves out into broad burning lakes, sometimes from 12 to 15 miles wide, and 100 feet deep. When the 'fiery lake' which filled up the lower portion of the valley of the Skaptâ had been augmented by new supplies, the lava flowed up the course of the river to the foot of the hills from whence the Skaptâ takes its rise. This affords a parallel case to one

which can be shown to have happened at a remote era in the volcanic region of the Vivarais in France, where lava issued from the cone of Thueyts, and while one branch ran down, another more powerful stream flowed up, the channel of the river Ardêche.

The sides of the valley of the Skaptâ present superb ranges of basaltic columns of older lavas, resembling those which are laid open in the valleys descending from Mont Dor in Auvergne, where more modern lava currents, on a scale very inferior in magnitude to those of Iceland, have also usurped the beds of the existing rivers. The eruption of Skaptár Jokul did not entirely cease till the end of two years; and when Mr. Paulson visited the tract eleven years afterwards, in 1794, he found columns of smoke (or vapour) still rising from parts of the lava, and several rents filled with hot water.*

Although the population of Iceland was very much scattered, and did not exceed 50,000, no less than twenty villages were destroyed, besides those inundated by water; and more than 9,000 human beings perished, together with an immense number of cattle, partly by the depredations of the lava, partly by the noxious vapours which impregnated the air, and, in part, by the famine caused by showers of ashes throughout the island, and the desertion of the coasts by the fish.

Immense volume of the lava.—But the extraordinary volume of melted matter produced in this eruption deserves the particular attention of the geologist. Of the two branches, which flowed in nearly opposite directions, the greater was 50, and the lesser 45 miles in length. The extreme breadth which the Skaptâ branch attained in the low countries was from 12 to 15 miles, that of the other about 7. The ordinary height of both currents was 100 feet, but in narrow defiles it sometimes amounted to 600. Professor Bischoff has calculated, that the mass of lava brought up from the subterranean regions by this single eruption 'surpassed in magnitude the bulk of Mont Blanc.' † But a more

* Henderson's Journal, &c., p. 228.

† Jameson's Phil. Journ. vol. xxvi. p. 291.

distinct idea will be formed of the dimensions of the two streams, if we consider how striking a feature they would now form in the geology of England, had they been poured out on the bottom of the sea after the deposition, and before the elevation of our secondary and tertiary rocks. The same causes which have excavated valleys through parts of our marine strata, once continuous, might have acted with equal force on the igneous rocks, leaving, at the same time, a sufficient portion undestroyed to enable us to discover their former extent. Let us, then, imagine the termination of the Skaptâ branch of lava to rest on the escarpment of the inferior and middle oolite, where it commands the vale of Gloucester. The great platform might be 100 feet thick, and from 10 to 15 miles broad, exceeding any which can be found in Central France. We may also suppose great tabular masses to occur at intervals, capping the summit of the Cotswold Hills between Gloucester and Oxford, by Northleach, Burford, and other towns. The wide valley of the Oxford clay would then occasion an interruption for many miles; but the same rocks might recur on the summits of Cumnor and Shotover Hills, and all the other oolitic eminences of that district. On the chalk of Berkshire, other tabular masses, 6 or 7 miles wide, might again be found; and, lastly, crowning the highest sands of Highgate and Hampstead, we might behold some remnants of the current 500 or 600 feet in thickness, causing those hills to rival, or even to surpass, in height, Salisbury Craigs and Arthur's Seat.

The distance between the extreme points here indicated would not exceed 90 miles in a direct line; and we might then add, at the distance of nearly 200 miles from London, along the coast of Dorsetshire and Devonshire, for example, a great mass of igneous rocks, to represent the submarine reef of the island of Nyöe. An eminent French writer declared in 1829 that *all* geological phenomena took place in ancient times on a scale of magnitude a hundredfold greater than those which are witnessed in our days, but it would be difficult to point out a mass of igneous rock of ancient date (distinctly referable to a single eruption) which

would even rival in volume the matter poured out from Skaptár Jokul in 1783.

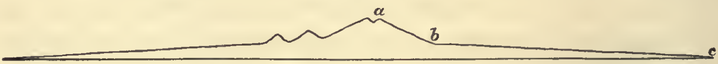
Eruption of Jorullo in 1759.—As another example of the stupendous scale of modern volcanic eruptions, I may mention that of Jorullo in Mexico, in 1759. The great region to which this mountain belongs has already been described. The plain of Malpais forms part of an elevated platform, between 2,000 and 3,000 feet above the level of the sea, and is bounded by hills composed of basalt, trachyte, and volcanic tuff, clearly indicating that the country had previously, though probably at a remote period, been the theatre of igneous action. From the era of the discovery of the New World to the middle of the last century, the district had remained undisturbed, and the space, now the site of the volcano, which is 36 leagues distant from the nearest sea, was occupied by fertile fields of sugar-cane and indigo, and watered by the two brooks Cuitimba and San Pedro. In the month of June, 1759, hollow sounds of an alarming nature were heard, and earthquakes succeeded each other for two months, until, at the end of September, flames issued from the ground, and fragments of burning rocks were thrown to prodigious heights. Six volcanic cones, composed of scoriæ and fragmentary lava, were formed on the line of a chasm which ran in the direction from N.N.E. to S.S.W. The least of these cones was 300 feet in height; and Jorullo, the central volcano, was elevated 1,600 feet above the level of the plain. It sent forth great streams of basaltic lava, containing included fragments of granitic rocks, and its ejections did not cease till the month of February, 1760.*

Humboldt visited the country more than forty years after this occurrence, and was informed by the Indians, that when they returned, long after the catastrophe, to the plain, they found the ground uninhabitable from the excessive heat. When he himself visited the place, there appeared, around the base of the cones, and spreading from them, as from a centre, over an extent of four square miles, a mass of matter of a convex form, about 550 feet high at its junction with the cones,

* Daubeny on Volcanos, p. 337.

and gradually sloping from them in all directions towards the plain. This mass was still in a heated state, the temperature in the fissures being on the decrease from year to year, but in 1780 it was still sufficient to light a cigar at the depth of a few inches. On this slightly convex protuberance, the slope of which must form an angle of about 6° with the horizon, were thousands of flattish conical mounds, from 6 to 9 feet high, which, as well as large fissures traversing the plain, acted as fumeroles, giving out clouds of sulphurous acid and hot aqueous vapour. The two small rivers before mentioned disappeared during the eruption, losing themselves

Fig. 95.



a. Summit of Jorullo. *b, c.* Inclined plane sloping at an angle of 6° from the base of the cones.

below the eastern extremity of the plain, and reappearing as hot springs at its western limit.

Cause of the convexity of the plain of Malpais.—Humboldt attributed the convexity of the plain to inflation from below; supposing the ground, for four square miles in extent, to have risen up in the shape of a bladder to the elevation of 550 feet above the plain in the highest part. But Mr. Scrope has suggested that the phenomena may be accounted for far more naturally by supposing that lava, flowing simultaneously from the different orifices and principally from Jorullo, formed, by the overflow of one sheet or stream upon another, a thick bed of imperfectly liquid basaltic lava, which acquired great thickness about its source, gradually thinning off towards the outer limits of the elliptical area which it covered, and thus producing a convex surface. Fresh supplies were probably emitted successively during the course of an eruption which lasted more than half a year; and some of these, resting on those first emitted, might only spread to a small distance from the foot of the cone, where they would necessarily accumulate to a great height. The average slope of the great dome-shaped volcanos of the Sandwich Islands, formed almost exclusively of lava, with scarce any scoriæ, is between 6° 30′ and 7° 46′, so that the inclination of the convex mass

around Jorullo, if we adopt Mr. Scrope's explanation (see fig. 95), is quite in accordance with the known laws which govern the flow of lava.

The showers, also, of loose and pulverulent matter from the six craters, and principally from Jorullo, would be composed of heavier and more bulky particles near the cones, and would raise the ground at their base, where, mixing with rain, they might have given rise to the stratum of black clay, which is described as covering the lava. The small conical mounds (called 'hornitos,' or little ovens) may resemble those five or six small hillocks which existed in 1823 on the Vesuvian lava, and sent forth columns of vapour, having been produced by the disengagement of elastic fluids heaving up small dome-shaped masses of lava. The fissures mentioned by Humboldt as of frequent occurrence, are such as might naturally accompany the consolidation of a thick bed of lava, contracting as it congeals; and the disappearance of rivers is the usual result of the occupation of the lower part of a valley or plain by lava, of which there are many beautiful examples in the old lava currents of Auvergne. The heat of the 'hornitos' is stated to have diminished from the first; and Mr. Bullock, who visited the spot many years after Humboldt, found the temperature of the hot spring very low, a fact which seems clearly to indicate the gradual congelation of a subjacent bed of lava, which from its immense thickness may have been enabled to retain its heat for half a century. The reader may be reminded, that when we thus suppose the lava near the volcano to have been, together with the ejected ashes, more than 500 feet in depth, we merely assign a thickness which the current of Skaptár Jokul attained in some places in 1783.

Hollow sound of the plain when struck.—Another argument adduced in support of the theory of inflation from below, was, the hollow sound made by the steps of a horse upon the plain; which, however, proves nothing more than that the materials of which the convex mass is composed are light and porous. The sound called 'rimbombo' by the Italians is very commonly returned by *made ground* when struck sharply; and has been observed not only on the sides of Vesuvius and

other volcanic cones where there is a cavity below, but in such regions as the Campagna di Roma, composed in a great measure of tuff and porous volcanic rocks. The reverberation, however, may perhaps be assisted by grottos and caverns, for these may be as numerous in the lavas of Jorullo as in many of those of Etna; but their existence would lend no countenance to the hypothesis of a great arched cavity, four square miles in extent, and in the centre 550 feet high.*

No recent eruptions of Jorullo.—In a former edition I stated that I had been informed by Captain Vetch, that in 1819 a tower at Guadalaxara was thrown down by an earthquake, and that ashes, supposed to have come from Jorullo, fell at the same time at Guanaxuato, a town situated 140 English miles from the volcano. But Mr. Burkhardt, a German director of mines, who examined Jorullo in 1827, ascertained that there had been no eruption there since Humboldt's visit in 1803. He went to the bottom of the crater, and observed a slight evolution of sulphurous acid vapours, but the 'hornitos' had entirely ceased to send forth steam. During the twenty-four years intervening between his visit and that of Humboldt, vegetation had made great progress on the flanks of the new hills, the rich soil of the surrounding country was once more covered with luxuriant crops of sugar-cane and indigo, and there was an abundant growth of natural underwood on all the uncultivated tracts.†

Galongoon, Java, 1822.—The mountain of Galongoon (or Galung Gung) was in 1822 covered by a dense forest, and situated in a fruitful and thickly-peopled part of Java. There was a circular hollow at its summit, but no tradition existed of any former eruption. In July, 1822, the waters of the river Kunir, one of those which flowed from its flanks, became for a time hot and turbid. On the following 8th of October a loud explosion was heard, the earth shook, and immense columns of hot water and boiling mud, mixed with burning brimstone, ashes, and lapilli, of the size of nuts, were projected from the mountain like a water-spout, with such

* See Scrope on Volcanos, p. 267.

† Leonhard and Bronn's Neues Jahrbuch, 1835, p. 36.

prodigious violence that large quantities fell beyond the river Tandoi, which is forty miles distant. Every valley within the range of this eruption became filled with a burning torrent, and the rivers, swollen with hot water and mud, overflowed their banks, and carried away great numbers of the people, who were endeavouring to escape, and the bodies of cattle, wild beasts, and birds. A space of twenty-four miles between the mountain and the river Tandoi was covered to such a depth with bluish mud that people were buried in their houses, and not a trace of the numerous villages and plantations throughout that extent was visible. Within this space the bodies of those who perished were buried in mud and concealed, but near the limits of the volcanic action they were exposed, and strewed over the ground in great numbers, partly boiled and partly burnt.

It was remarked, that the boiling mud and cinders were projected with such violence from the mountain, that while many remote villages were utterly destroyed and buried, others much nearer the volcano were scarcely injured.

The first eruption lasted nearly five hours, and on the following days the rain fell in torrents, and the rivers, densely charged with mud, deluged the country far and wide. At the end of four days (October 12th), a second eruption occurred more violent than the first, in which hot water and mud were again vomited, and great blocks of basalt were thrown to the distance of 7 miles from the volcano. There was at the same time a violent earthquake, and in one account it is stated that the face of the mountain was utterly changed, its summit broken down, and one side, which had been covered with trees, became an enormous gulf in the form of a semicircle. This cavity was about midway between the summit and the plain, and surrounded by steep rocks, said to be newly heaped up during the eruption. New hills and valleys are said to have been formed, and the rivers Banjarang and Wulna changed their course, and in one night (October 12th) 2,000 persons were killed.

The first intimation which the inhabitants of Bandong received of this calamity, on October 8th, was the news that the river Wulna was bearing down into the sea the dead

bodies of men, and the carcases of stags, rhinoceroses, tigers, and other animals. The Dutch painter Payen determined to travel from thence to the volcano, and he found that the quantity of the ashes diminished as he approached the base of the mountain. He alludes to the altered form of the mountain after the 12th, but does not describe the new semicircular gulf on its side.

The official accounts state that 114 villages were destroyed, and above 4,000 persons killed.*

Submarine volcanos.—Although we have every reason to believe that volcanic eruptions as well as earthquakes are common in the bed of the sea, it was not to be expected that many opportunities would occur to scientific observers of witnessing the phenomena. The crews of vessels have sometimes reported that they have seen in different places sulphurous smoke, flame, jets of water, and steam, rising up from the sea, or they have observed the waters greatly discoloured, and in a state of violent agitation as if boiling. New shoals have also been encountered, or a reef of rocks just emerging above the surface, where previously there was always supposed to have been deep water. On some few occasions the gradual formation of an island by submarine eruption has been observed, as that of Sabrina, in the year 1811, off St. Michael's in the Azores. The throwing up of ashes in that case, and the formation of a cone about 300 feet in height, with a crater in the centre, closely resembled the phenomena usually accompanying a volcanic eruption on land. Sabrina was soon washed away by the waves. Previous eruptions in the same part of the sea were recorded to have happened in 1691 and 1720. The rise of Nyöe, also, a small island off the coast of Iceland, in 1783, has already been alluded to; and another volcanic isle was produced by an eruption near Reikiavig, on the same coast, in June 1830.†

Graham Island,‡ 1831.—We have still more recent and

* Van der Boon Mesch, de Incendiis Montium Javæ, &c. Lugd. Bat. 1826; and Official Report of the President, Baron Van der Capellan; also, Von Buch, Isles Canar., p. 424.

† Journ. de Géol. tome i.

‡ In a former edition, I selected the name of Sciacca out of seven which had been proposed; but the Royal and Geographical Societies have now adopted

minute information respecting the appearance, in 1831, of a new volcanic island in the Mediterranean, between the S.W. coast of Sicily and that projecting part of the African coast where ancient Carthage stood. The site of the island was not any part of the great shoal, or bank, called 'Nerita,' as was first asserted, but a spot where Captain (Admiral) W. H. Smyth had found, in his survey a few years before, a depth of more than 100 fathoms' water.*

The position of the island (lat. 37° 1′ 30″ N., long. 12° 42′ 15″ E.) was about 30 miles S.W. of Sciacca, in Sicily, and 33 miles N.E. of the Island of Pantellaria.† On June 28, about a fortnight before the eruption was visible, Sir

Fig. 96.

Form of the cliffs of Graham Island, as seen from S.S.E., distant one mile, 7th August, 1831.‡

Pulteney Malcolm, in passing over the spot in his ship, felt the shocks of an earthquake, as if he had struck on a sand-bank; and the same shocks were felt on the west coast of Sicily, in a direction from S.W. to N.E. About July 10, John Corrao, the captain of a Sicilian vessel, reported that, as he passed near the place, he saw a column of water like a water-spout 60 feet high, and 800 yards in circumference, rising from the sea, and soon afterwards a dense steam in its place, which ascended to the height of 1,800 feet. The same Corrao, on his return from Girgenti, on July 18, found a small island, 12 feet high, with a crater in its centre, ejecting

Graham Island; a name given by Capt. Senhouse, R.N., the first who succeeded in landing on it. The seven rival names are Nerita, Ferdinanda, Hotham, Graham, Corrao, Sciacca, Julia. As the isle was visible for only about three months, this is an instance of a wanton multiplication of synonyms which has scarcely ever been outdone even in the annals of zoology and botany.

* Phil. Trans. 1832, p. 255.

† Journ. of Roy. Geograph. Soc. 1830–31.

‡ Phil. Trans., part ii., 1832, reduced from drawings by Captain Wodehouse, R.N.

volcanic matter, and immense columns of vapour; the sea around being covered with floating cinders and dead fish. The scoriæ were of a chocolate colour, and the water which boiled in the circular basin was of a dingy red. The eruption

Fig. 97.

View of the interior of Graham Island, 29th Sept. 1831.

continued with great violence to the end of the same month; at which time the island was visited by several persons, and among others by Capt. Swinburne, R.N., and M. Hoffmann,

Fig. 98.

Graham Island, 29th Sept. 1831.*

the Prussian geologist. It was then from 50 to 90 feet in height, and ¾ of a mile in circumference. By August 4 it

* In the annexed sketch (fig. 98), drawn by M. Joinville, who accompanied M. C. Prevost, the beds seem to slope towards the centre of the crater; but I am informed by M. Prevost that these lines were not intended by the artist to represent the dip of the beds.

became, according to some accounts, above 200 feet high, and 3 miles in circumference; after which it began to diminish in size by the action of the waves, and was only 2 miles round on August 25; and on September 3, when it was carefully examined by Captain Wodehouse, only $\frac{3}{5}$ of a mile in circumference; its greatest height being then 107 feet. At this time the crater was about 780 feet in circumference. On September 29, when it was visited by Mons. C. Prevost, the circumference of the island was reduced to about 700 yards. It was composed entirely of incoherent ejected matter, scoriæ, pumice, and lapilli, forming regular strata, some of which are described as having been parallel to the steep inward slope of the crater, while the rest were inclined outwards, like those of Vesuvius.* When the arrangement of the ejected materials has been determined by their falling continually on two steep slopes, that of the external cone and that of the crater, which is always a hollow inverted cone, a

Fig. 99.

transverse section would probably resemble that given in the annexed figure (99). But when I visited Vesuvius, in 1828, I saw no beds of scoriæ inclined towards the axis of the cone. (See fig. 73, Vol. I. p. 632.) Such may have once existed; but the explosions or subsidences, or whatever causes produced the great crater of 1822, had possibly destroyed them.

Few of the pieces of stone thrown out from Graham Island exceeded a foot in diameter. Some fragments of dolomitic limestone were intermixed; but these were the only non-volcanic substances. During the month of August, there occurred on the S.W. side of the new island a violent ebullition and agitation of the sea, accompanied by the constant ascension of a column of dense white steam, indicating the existence of a second vent at no great depth from the surface. Towards the close of October, no vestige of the crater remained, and the island was nearly levelled with the surface of the ocean, with the exception, at one point, of a small

* See Memoir by M. C. Prevost, Ann. des Sci. Nat. tom. xxiv.

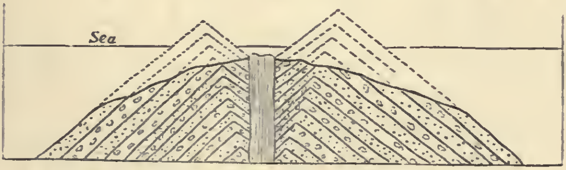
monticule of sand and scoriæ. It was reported that, at the commencement of the year following (1832), there was a depth of 150 feet where the island had been: but this account was quite erroneous; for in the early part of that year Captain Swinburne found a shoal and discoloured water there, and towards the end of 1833 a dangerous reef existed of an oval figure, about $\frac{3}{5}$ of a mile in extent. In the centre was a black rock, of the diameter of about 26 fathoms, from 9 to 11 feet under water; and round this rock were banks of black volcanic stones and loose sand. At the distance of 60 fathoms from this central mass, the depth increased rapidly. There was also a second shoal at the distance of 450 feet S.W. of the great reef, with 15 feet water over it, also composed of rock, surrounded by deep sea. We can scarcely doubt that the rock in the middle of the larger reef is solid lava, which rose up in the principal crater, and that the second shoal marks the site of the submarine eruption observed in August, 1831, to the S.W. of the island.

From the whole of the facts above detailed, it appears that a hill 800 feet or more in height was formed by a submarine volcanic vent, of which the upper part (only about 200 feet high) emerged above the waters, so as to form an island. This cone must have been equal in size to one of the largest of the lateral volcanos on the flanks of Etna, and about half the height of the mountain Jorullo in Mexico, which was formed in the course of nine months, in 1759. In the centre of the new volcano a large cavity was kept open by gaseous discharges, which threw out scoriæ; and fluid lava probably rose up in this cavity. It is not uncommon for small subsidiary craters to open near the summit of a cone, and one of these may have been formed in the case of Graham Island; a vent perhaps, connected with the main channel of discharge, which gave passage in that direction to elastic fluids, scoriæ, and melted lava. It does not appear that, either from this duct, or from the principal vent, there was any overflowing of lava; but melted rock may have flowed from the flanks or base of the cone (a common occurrence on land), and may have spread in a broad sheet over the bottom of the sea.

The dotted lines in the annexed figure (fig. 100) are an imaginary restoration of the upper part of the cone, now removed by the waves: the strong lines represent the part of the volcano which is still under water: in the centre is a great column or dike, of solid lava, 200 feet in diameter, supposed to fill the space by which the gaseous fluids rose; and on each side of the dike is a stratified mass of scoriæ and fragmentary lava. The solid nucleus of the reef, where the black rock is now found, withstands the movements of the sea; while the surrounding loose tuffs are cut away to a somewhat lower level. In this manner the lava, which was the lowest part of the island, or, to speak more correctly, which scarcely ever rose above the level of the sea when the island existed, has now become the highest point in the reef.

No appearances observed, either during the eruption or since the island disappeared, give the least support to the

Fig. 100.



Supposed section of Graham Island. (C. Maclaren.*)

opinion promulgated by some writers, that part of the ancient bed of the sea had been lifted up bodily.

The solid products, says Dr. John Davy, whether they consisted of sand, light cinders, or vesicular lava, differed more in form than in composition. The lava contained augite; and the specific gravity was 2·07 and 2·70. When the light spongy cinder, which floated on the sea, was reduced to fine powder by trituration, and the greater part of the entangled air got rid of, it was found to be of the specific gravity 2·64; and that of some of the sand which fell in the eruption was 2·75; † so that the materials equalled ordinary granite in weight and solidity. The only gas evolved in any considerable quantity was carbonic acid.‡

* Geol. of Fife and the Lothians, p. 41. Edin. 1839.

† Phil. Trans. 1832, p. 243.

‡ Ibid. p. 249.

Submarine eruptions in mid-Atlantic.—In the Nautical Magazine for 1835, p. 642, and for 1838, p. 361, and in the Comptes Rendus, April 1838, accounts are given of a series of volcanic phenomena, earthquakes, troubled water, floating scoriæ and columns of smoke, which have been observed at intervals since the middle of the last century, in a space of open sea between longitudes 20° and 22° west, about half a degree south of the equator. These facts, says Mr. Darwin, seem to show, that an island or an archipelago is in process of formation in the middle of the Atlantic: a line joining St. Helena and Ascension would, if prolonged, intersect this slowly nascent focus of volcanic action.* Should land be eventually formed here, it will not be the first that has been produced by igneous action in this ocean since it was inhabited by the existing species of testacea. At Porto Praya, in St. Jago, one of the Azores, a horizontal calcareous stratum occurs, containing shells of *recent* marine species, covered by a great sheet of basalt, 80 feet thick.† It would be difficult to estimate too highly the commercial and political importance which a group of islands might acquire, if in the next two or three thousand years they should rise in mid-ocean between St. Helena and Ascension.

Eruption in Lancerote, 1730 *to* 1736.—An eruption happened in Lancerote, one of the Canary Islands, between the years 1730 and 1736, of which a detailed description was published by Von Buch, who visited that island in 1815, and compared the accounts transmitted to us of the event, with the present state and geological appearances of the country. During this outbreak, which lasted for five successive years, the flourishing town of St. Catalina and several other places were buried under lava and scoriæ 400 feet in thickness. Thirty cones were thrown up arranged in one line running nearly east and west and extending for a length of two geographical miles. The most elevated of these hills reached a height of about 600 feet above its base. The subterranean cleft from which elastic fluids escaped seems to have opened or widened at a succession of new points when the first apertures had become obstructed by solid lava or ejected

* Darwin's Volcanic Islands, p. 92. † Ibid. p. 6.

matter. From one of the fissures which was still open in 1815 Von Buch found hot vapours issuing which raised the thermometer to 145° Fahr., and were probably at the boiling point lower down. The exhalations seemed to consist of aqueous vapour; yet they could not be pure steam, for the crevices were encrusted on either side by siliceous sinter (an opal-like hydrate of silica of a white colour), which extended almost to the middle. This important fact attests the length of time during which chemical processes continue after eruptions, and shows how open fissures may be filled up by mineral matter, sublimed from volcanic exhalations.

The quantity of dead fish which were strewed over the banks and shores of the island or floated on the waters on more than one occasion during this series of eruptions, some of them of species which had never before been observed, is said to have been indescribably great, especially where streams of lava entered the sea. This fact is one of geological interest, since many of the fossil fishes of ancient date, those of Monte Bolca for example, are preserved in volcanic tuff or in marls associated with contemporaneous igneous rocks. In August 1824 another eruption happened in Lanzerote near the port of Rescif, forming a cone and crater from which Mr. Hartung found hot vapours escaping during his visit in 1850.*

SANTORIN.

The Gulf of Santorin, in the Grecian Archipelago, has been for 2,000 years a scene of active volcanic operations. The largest of the three outer islands of the group (to which the general name of Santorin is given) is called Thera (or sometimes Santorin), and forms more than two-thirds of the circuit of the gulf. (See Map, fig. 101, p. 66.) The length of the exterior coast-line of this and the other two islands named Therasia and Aspronisi, taken together, amounts to about 30 miles, and that of the inner coast-line of the same islands to about 18 miles. In the middle of the gulf are three other islands, called the Little, the New, and the Old 'Kaimenis,' or 'Burnt Islands.' The accompanying

* G. Hartung, Lanzerote und Fuertaventura. 1856.

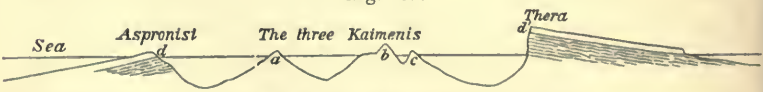
Fig. 101.

Map of Santorin, in the Grecian Archipelago, from a Survey in 1848, by Captain Graves, R.N.

The soundings are given in fathoms.

A. Shoal formed by submarine volcanic eruption in 1650.
B. Northern entrance.
C. Mansell's Rock.
D. Mount St. Elias, 1,887 feet high.

Fig. 102.



Section of Santorin, in a N.E. and S.W. direction, from Thera through the Kaimenis to Aspronisi.

a. Old Kaimeni.
b. New Kaimeni.
c. Little Kaimeni.
d, d'. Great covering of white tufaceous agglomerate or of ejected matter containing fragments of brown trachyte.

map has been reduced from an Admiralty survey executed in 1848 by the late Captain Graves, R.N.

Pliny informs us that the year 186, B.C., gave birth to the Old Kaimeni, also called Hiera, or the 'Sacred Isle;' and in the year 19 of our era 'Theia' (the Divine) made its appearance above water, and was soon joined by subsequent eruptions to the older island, from which it was only 250 paces distant. The Old Kaimeni also increased successively in size in 726 and in 1427. A century and a half later, in 1573, another eruption produced the cone and crater called Micra-Kaimeni, or 'the Small Burnt Island.' The next great event which we find recorded occurred in 1650, when a submarine outbreak violently agitated the sea, at a point 3½ miles to the N.E. of Thera, and which gave rise to a shoal (see A in the Map) carefully examined during the survey of 1848 by Captain Graves, and found to have 10 fathoms water over it, the sea deepening around it in all directions. This eruption lasted three months, covering the sea with floating pumice. At the same time an earthquake destroyed many houses in Thera, while the sea broke upon the coast, overthrew two churches, and exposed to view two villages, one on each side of the mountain of St. Stephen, both of which must have been overwhelmed by showers of volcanic matter during some previous eruptions of unknown date.* The accompanying evolution of sulphur and hydrogen issuing from the sea killed more than 50 persons, and above 1,000 domestic animals. A wave, also, 50 feet high, broke upon the rocks of the Isle f Nia, about 4 leagues distant, and advanced 450 yards to the interior of the Island of Sikino. Lastly, in 1707 and 09, Nea-Kaimeni, or the New Burnt Island, was formed ween the two others, Palaia and Micra, the Old and Little s. This isle was composed originally of two distinct ; the first which rose was called the White Island, osed of a mass of pumice, extremely porous. Goree, the , who was then in Santorin, says that the rock 'cut like bread,' and that, when the inhabitants landed on it, they found a multitude of full-grown fresh oysters adhering

* Virlet, Bull. de la Soc. Géol. de France, tom iii. p. 103.

to it, which they ate.* This mass was afterwards covered, in great part, by the matter ejected from the crater of a twin-island formed simultaneously, and called Black Island, consisting of brown trachyte. The trachytic lava which rose on this spot appears to have been a long time in an intumescent state, for the New Kaimeni was sometimes lowered on one side while it gained height on the other, and rocks rose up in the sea at different distances from the shore and then disappeared again. The eruption was renewed at intervals during the years 1711 and 1712, and at length a cone was piled up to the height of about 330 feet above the level of the sea, its exterior slope forming an angle of 33° with the horizon, and the crater on its summit being 80 yards in diameter. In addition to the two points of subaërial eruption on the New and Little Kaimenis, two other cones, indicating the sites of submarine outbursts of unknown date, were discovered under water near the Kaimenis during the late survey.

In regard to the 'White Island,' which was described and visited by Goree in 1707, we are indebted to Mr. Edward Forbes for having, in 1842, carefully investigated the layer of pumiceous ash of which it is constituted. He obtained from it many shells of marine genera, Pectunculus, Arca, Cardita, Trochus, and others, both univalve and bivalve, all of recent Mediterranean species. They were in a fine state of preservation, the bivalves with the epidermis remaining, and valves closed, showing that they had been suddenly destroyed. Mr. Forbes, from his study of the habits of the mollusca living at different depths in the Mediterranean, was able to decide that such an assemblage of species could not have lived at a less depth than 220 feet, so that a bodily upheaval of the mass to that amount must have taken place in order to bring up this bed of ashes and shells to the level of the sea, and they now rise 5 or 6 feet above that level.†

We may compare this partial elevation of solid matter to the rise of a hardened crust of scoriæ, such as is usually

* Phil. Trans. No. 332.

† E. Forbes, Brit. Association, Report for 1843, p. 177.

formed on the surface of lava currents, even while they are in motion, and which, although stony and capable of supporting heavy weights, may be upraised without bursting by the intumescence of the melted matter below. The reader may also be reminded of the upheaval of a solid crust of lava witnessed by Abich within the crater of Vesuvius in the year 1834, already mentioned by me. (Vol. I. p. 630.) That the upheaval was merely local is proved by the fact that the neighbouring Kaimenis did not participate in the movement, still less the three more distant or outer islands.

Fig. 103.

Bird's-eye view of the Gulf of Santorin during the volcanic eruption of February, 1866.

a. Therasia.
b. The 'northern entrance,' 1,068 feet deep.
c. Thera.
d. Mount St. Elias, rising 1,887 feet above the sea, composed of granular limestone and clay-slate, the only non-volcanic rocks in Santorin.
e. Aspronisi.
f. Little Kaimeni.
g. New Kaimeni.
h. Old Kaimeni.
i. Aphroessa.
k. George.

Eruption of 1866.—Another eruption broke out in Nea-Kaimeni in February 1866. At the end of January the sea had been observed in a state of ebullition off the south-west coast, and part of the channel between New and Old Kaimeni marked 70 fathoms in the Admiralty chart had become, on February 11, only 12 fathoms deep. According to M. Julius Schmidt, a gradual rising of the bottom went on until

a small island made its appearance, called afterwards Aphroessa.* (See *i*, fig. 103.) It seems to have consisted of lava pressed upwards and outwards almost imperceptibly by steam, which was escaping at every pore through the hissing scoriaceous crust. 'It could be seen,' says Commander Lindsay Brine, R.N., 'through the fissures in the cone that the rocks within were red-hot, but it was not till later that an eruption began.'† On February 11, the village of Vulcano, on the south-east coast, where there had been a partial sinking of the ground, was in great part overwhelmed by the materials cast out from a new vent which opened in that neighbourhood, and to which the name of George was given (see *k*, fig. 103), which finally, according to Schmidt, became about 200 feet high. Commander Brine having ascended on February 28, 1866, to the top of the crater of Nea-Kaimeni, about 350 feet high, looked down upon the new vent then in full activity. The whole of the cone was swaying with an undulating motion to the right and left, and appeared sometimes to swell to nearly double its size and height, to throw out ridges like mountain spurs, till at last a broad chasm appeared across the top of the cone, accompanied by a tremendous roar of steam, and the shooting up from the new crater to the height of from 50 to 100 feet of tons of rock and ash mixed with smoke and steam. Some of these which fell on Micra-Kaimeni at a distance of 600 yards from the crater, measured 30 cubic feet. This effort over, the ridges slowly subsided, the cone lowered and closed in, and then, after a few minutes of comparative silence, the struggle would begin again with precisely similar sounds, action, and result. Threads of vapour escaping from the old crater of Nea-Kaimeni proved that there was a subterranean connection between the old and new vents.'‡

Aphroessa, of which the cone was at length raised to a height of more than 60 feet, was united in August with the main island. This was due in part at least to the upheaval of the bottom of the sea, which is now only 7 fathoms deep

* Schmidt, cited by Von Hauer.

† Brine, Visit to Santorin. Royal Geographical Proc. Nov. 10th, 1866, vol. x. p. 317.

‡ Ibid.

in the channel dividing the New and Old Kaimenis, whereas in the Admiralty chart (see fig. 101, p. 66) the soundings gave 100 fathoms.

It will be seen by the map and section (figs. 101 and 102), that the Kaimenis are arranged in a linear direction, running N.E. and S.W., in a manner different from that represented in the older charts. In their longest diameter they form at their base a ridge nearly bisecting the gulf or crater.

Notwithstanding this linear arrangement we may compare the three Kaimenis in the centre of the gulf to the modern cone of Vesuvius, and consider the outer islands Thera, Aspronisi, and Therasia as the remains of an older and ruined cone like Somma. Thera, which constitutes alone more than two-thirds of the outer circuit, presents everywhere towards the gulf high and steep precipices composed of volcanic rocks. In all places near the base of its cliffs, a depth of from 800 to 1,000 feet of water was found, and Lieut. Leycester informs us that if the gulf, which is 6 miles in diameter, could be drained, a bowl-shaped cavity would appear with walls 2,449 feet high in some places, and even on the south-west side, where it is lowest, nowhere less than 1,200 feet high; while the Kaimenis would be seen to form in the centre a huge mountain 5½ miles in circumference at its base, with three principal summits (the Old, the New, and the Little Burnt Islands) rising severally to the heights of 1,251, 1,629, and 1,158 feet above the bottom of the abyss. The rim of the great cauldron thus exposed would be observed to be in all parts perfect and unbroken, except at one point where there is a deep and long chasm or channel, known by mariners as the 'northern entrance' (B, fig. 101, and *b*, fig. 103), between Thera and Therasia, and called by Lieut. Leycester 'the door into the crater.' It is no less than 1,170 feet deep, and constitutes, as will appear by the soundings (see Map, fig. 101), a remarkable feature in the bed of the sea. There is no corresponding channel passing out from the gulf into the Mediterranean at any other point in the circuit between the outer islands, the greatest depth there ranging from 7 to 66 feet.

We may conceive, therefore, if at some former time the

whole mass of Santorin stood at a higher level by 1,200 feet, that this single ravine or narrow valley now forming 'the northern entrance,' was the passage by which the sea entered a circular bay.

But at a still earlier period when the ancient volcanic cone, of which the outer islands are the remains, was still more elevated above the level of the sea, there may have been a deep valley of subaërial erosion cut by the principal river which then drained Santorin, which may have consisted of one lofty volcanic cone afterwards truncated by a paroxysmal explosion such as we have already spoken of in the case of Galongoon, p. 57, and when treating of the supposed origin of the Val del Bove on Etna. It would then be necessary to imagine the subsidence and partial submergence of this original island in order to explain the present gulf and the deep channel (B, fig. 101) coinciding with the ancient gorge of fluviatile erosion.

All the outer islands Thera, Therasia, and Aspronisi are covered with one great uniform mass of volcanic matter, expressed by d, d', in the section, fig. 102, p. 66. This great overlying deposit has been called pumiceous by many observers, but M. Virlet says it is a white tufaceous agglomerate through which are dispersed fragments of a brown trachyte. Such a mass may well be imagined to be the product of that paroxysmal eruption by which so large a part of the great cone was destroyed, and the gulf formed, in the middle of which the Kaimenis have since been thrown up.

Thera, Therasia, and Aspronisi are exclusively composed of volcanic matter, except the southern part of Thera, where Mount St. Elias (d d, fig. 103) reaches an elevation of 1,887 feet above the sea, or three times the height now attained by the loftiest of the igneous rocks.* This mountain is formed of granular limestone and argillaceous schist, and is much more ancient than any part of the volcanic cone, one side of the base of which now abuts against it. The inclination, strike, and fractures of the calcareous and argillaceous strata of St. Elias have no relation to the great cone, but, according

* Virlet, Bull. de la Soc. Géol. de France, tome iii. p. 103.

to M. Bory St. Vincent, have the same direction as those of the other isles of the Grecian Archipelago, namely, from N.N.W. to S.S.E. Each of the three islands, Thera, Therasia, and Aspronisi, are composed of beds of trachytic lava and tuff, having a gentle inclination of only 3° or 4°. Each bed is very narrow and discontinuous, the successive layers being moulded or dove-tailed, as M. Virlet expresses it, into the inequalities of the previously existing surface, on which showers of cinders or streams of melted matter had been poured.

An important fact is adduced by M. Virlet, to show that the gentle dip of the lava streams in the three outer islands towards all points of the compass, away from the centre of the gulf, has not been due to the upheaval of horizontal beds, as conjectured by Von Buch, who had never visited Santorin.* The French geologist found that the vesicles or pores of the trachytic masses were lengthened out in the several directions in which they would have flowed if they had descended from the axis of a cone occupying the centre of the crater. For it is well known that the bubbles of confined gas in a fluid in motion assume an oval form, and the direction of their longer axis coincides always with that of the stream.

The absence of dikes in the cliffs surrounding the gulf is in favour of the theory that we here behold a section of the basal remains of an old volcanic cone. We have already spoken of the want of such dikes in those parts of the old Vesuvius (see Vol. I. p. 636) or Somma, as well as of Mount Etna, which are far from the original centres of eruption. (Vol. II. p. 17.) We may confidently infer from analogy that the missing part of the old cone of Santorin which rose to a great height where the Kaimenis now stand, consisted of steeply inclined lavas traversed by numerous vertical dikes.

If we adopt the hypothesis above suggested, we are required to assume a subsidence of more than 1,000 feet in order to explain the north-east channel (B, fig. 101, and *b*, fig. 103) as being a submerged valley or ravine of subaërial erosion. In reference to this point we may mention that a large part of Thera actually sank down during a great earthquake in

* Poggendorf's Annalen, 1836, p. 183.

1650, the subsidence being proved not only by tradition, but by the fact that a road which formerly led between two places on the east coast of Thera is now 12 fathoms under water. A long succession, no doubt, of such events would be demanded to bring about so great a submergence, and future geologists will have to decide whether this or some other theory will best account for this submarine chasm.

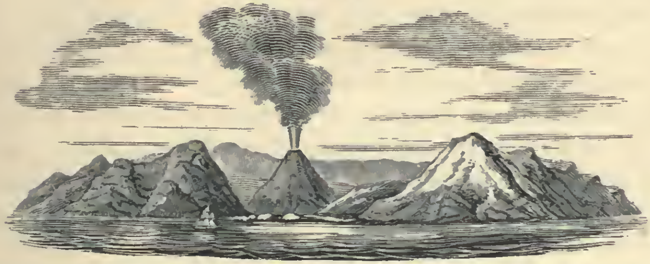
On a review, therefore, of all the facts now brought to light respecting Santorin, I attribute the moderate slope of the beds in Thera and the other external islands to their having originally descended the inclined flanks of a large volcanic cone, the principal orifice or vents of eruption having been always situated where they are now, in or near the centre of the space occupied by the gulf or crater, in other words where the outburst of the Kaimenis has been witnessed in historical times. The single long and deep opening into the crater is a feature common to all those remnants of ancient volcanos, the central portions of which have been removed, and is probably connected with aqueous denudation. As to the age of the more ancient volcanic formations of Santorin, I am informed by M. Fouqué that they belong to the Newer Pliocene period, as shown by marine shells which he collected in 1866.*

Barren Island.—There is a great analogy between the structure of Barren Island in the Bay of Bengal, lat. 12° 15′, and that of Santorin last described. When seen from the ocean, this island presents, on almost all sides, a surface of bare rocks, rising, with a moderate acclivity, towards the interior; but at one point there is a cleft by which we can penetrate into the centre, and there discover that it is occupied by a great circular basin more than 8,000 feet in diameter bordered all around by steep rocks, in the midst of which rises a volcanic cone, very frequently in eruption. The height of the circular border which encloses the basin has been variously estimated. According to Von Liebig, who visited the island in 1857, it was about 1,000 feet high, corresponding in elevation to the modern cone, so that the latter can only be seen from the sea

* Splendid photographs and descriptions of the eruption of the Kaimenis in 1866 have been published by Messrs. Fritsch, Reiss, and Stübel. Trübner, London, 1867.

by looking through the ravine. The sides of this cone slope at angles of from 35° to 40°. In some of the older accounts the sea is described as entering the inner basin, but Von Liebig says it was excluded at the time of his visit, and that a stream of black lava 10 feet high was traceable from the interior

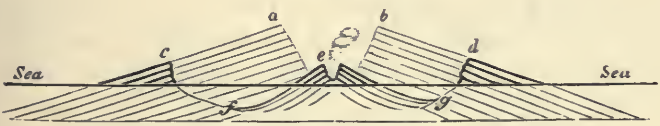
Fig. 104.



Cone and crater of Barren Island, in the Bay of Bengal. Height of the central cone (according to Capt. Miller, in 1834), 500 feet.*

to the outlet; there was also on the sides of the passage or inlet a raised beach 20 feet high, composed of volcanic tuff and rolled pebbles, indicative of a modern upheaval of the island to that extent. It is most probable that the exterior enclosure of Barren Island (*c*, *d*, fig. 105) is nothing more than

Fig. 105.



Supposed section of Barren Island, in the Bay of Bengal.

the remains of a truncated cone, *c*, *a*, *b*, *d*, a great portion of which has been removed by explosion, which may have preceded the formation of the new interior cone *f*, *e*, *g*.†

MUD VOLCANOS.

Iceland.—Professor R. Bunsen, in his account of the pseudo-volcanic phenomena of Iceland, describes many valleys where sulphurous and aqueous vapours burst forth

* The annexed view is given by Von Buch. Captain Horsburgh saw smoke proceeding from the crater in 1803.

† Von Liebig, Zeitschrift der Geologischen Gesellschaft, vol. x. p. 303. 1858.

with a hissing sound, from the hot soil formed of volcanic tuff. In such spots a pool of boiling water is seen, in which a bluish-black argillaceous paste rises in huge bubbles. These bubbles on bursting throw the boiling mud to a height of 15 feet and upwards, so that it accumulates in ledges round the crater or basin of the spring.

Baku, on the Caspian.—The formation of a new mud volcano was witnessed on November 27, 1827, at Tokmali, on the peninsula of Abscheron, east of Baku. Flames blazed up to an extraordinary height, for a space of 3 hours, and continued for 20 hours more to rise about 3 feet above a crater, from which mud was ejected. At another point in the same district where flames issued, fragments of rock of large size were hurled up into the air and scattered around.*

Sicily.—At a place called Macaluba, near Girgenti in Sicily, are several conical mounds from 10 to 30 feet in height, with small craters at their summits, from which cold water, mixed with mud and bitumen, is cast out. Bubbles of carbonic acid and carburetted hydrogen gas are also disengaged from these springs, and at certain periods with such violence as to throw the mud to the height of 200 feet. These 'air volcanos,' as they are sometimes termed, are known to have been in the same state of activity for the last 15 centuries; and Dr. Daubeny imagines that the gases which escape may be generated by the slow combustion of beds of sulphur, which is actually in progress in the blue clay, out of which the springs rise.† But as the gases are similar to those disengaged in volcanic eruptions, and as they have continued to stream out for so long a period, they may perhaps be derived from a more deeply-seated source.

Beila, in India.—In the district of Luss or Lus, south of Beila, about 120 miles N.W. of Cutch and the mouths of the Indus (see Map, fig. 111, p. 98), numerous mud volcanos are scattered over an area of probably not less than 1,000 square miles. Some of these have been well described by Captain Hart, and subsequently by Captain Robertson, who has paid a visit to that region, and made sketches of them, which he has kindly placed at my disposal. From one of

* Humboldt's Cosmos.

† Daubeny, Volcanos, p. 267.

these the annexed view has been selected. These conical hills occur to the westward of the Hara Mountains and the river Hubb. (See Map, p. 98.) One of the cones is 400 feet high, composed of light-coloured earth, and having at its summit a crater 30 yards in diameter. The liquid mud which fills the crater is continually disturbed by air-bubbles, and here and there is cast up in small jets.*

Fig. 106.

Mud cones and craters of Hinglaj, near Beila, district of Lus, 120 miles north-west of mouth of the Indus. From original drawing by Capt. Robertson. (See Map, p. 98.)

Frequency of eruptions, and nature of subterranean igneous rocks.—When we speak of the igneous rocks of our own times, we mean that small portion which, during volcanic eruptions, reaches the surface, whether in the form of lava, scoriæ, or sand, being forced up from the interior by elastic fluids in a melted state, and cooling gradually in the sea or open air.

* See Buist, Volcanos of India, Trans. Bombay Geol. Soc. vol. x. p. 154, and Captain Robertson, Journ. of Roy. Asiat. Soc. 1850.

But we cannot obtain access to that which is congealed far beneath the surface under a pressure equal to that of many hundred, or many thousand, atmospheres.

During the last century, about 50 eruptions are recorded of the five European volcanic districts, of Vesuvius, Etna, Volcano (one of the Lipari Isles), Santorin, and Iceland; but many beneath the sea in the Grecian Archipelago and near Iceland may doubtless have passed unnoticed. If some of them produced no lava, others, on the contrary, like that of the Skaptár Jokul, in 1783, poured out melted matter for 5 or 6 years consecutively; which cases, being reckoned as single eruptions, will compensate for those of inferior strength. Now, if we consider the active volcanos of Europe to constitute about a fortieth part of those already known on the globe, and calculate that, one with another, they are about equal in activity to the burning mountains in other districts, we may then compute that there happen on the earth about 2,000 eruptions in the course of a century, or about 20 every year.

However inconsiderable, therefore, those rocks may be which the operations of fire produce on the surface, we must suppose the subterranean changes now constantly in progress to be on the grandest scale. The loftiest volcanic cones and the lavas which have flowed from their craters must be insignificant when contrasted with the products of heat in the nether regions. In regard to these last or those igneous rocks which have been formed in our own times in the bowels of the earth, whether in rents and caverns, or by the cooling of lakes of melted lava, we may safely infer that they are heavier and less porous than ordinary lavas, and more crystalline, although composed of the same mineral ingredients. As the hardest crystals produced artificially in the laboratory require the longest time for their formation, so we must suppose that where the cooling down of melted matter takes place by insensible degrees, in the course of ages, a variety of minerals will be produced far harder than any formed by natural processes within the short period of human observation.

These subterranean volcanic rocks, moreover, cannot be stratified in the same manner as sedimentary deposits from

water, although it is evident that when great masses consolidate from a state of fusion, they may separate into natural divisions; for this is seen to be the case in many lava currents. We may also expect that the rocks in question will often be rent by earthquakes, since these are common in volcanic regions; and the fissures will be often injected with similar matter, so that dikes of crystalline rock will traverse masses of similar composition. It is also clear, that no organic remains can be included in such masses, as also that these deep-seated igneous formations considered in mass must underlie all the strata containing organic remains, because the heat proceeds from below upwards, and the intensity required to reduce the mineral ingredients to a fluid state must destroy all organic bodies in rocks included in the midst of them.

If by a continued series of elevatory movements, such masses shall hereafter be brought up to the surface, in the same manner as sedimentary marine strata have, in the course of ages, been upheaved to the summit of the loftiest mountains, it is not difficult to foresee what perplexing problems may be presented to the geologist. He may then, perhaps, study in some mountain-chain the very rocks produced at the depth of several miles beneath the Andes, Iceland, or Java, in the time of Leibnitz, and draw from them the same conclusion which that philosopher derived from certain igneous products of high antiquity; for he conceived our globe to have been, for an indefinite period, in the state of a comet, without an ocean, and uninhabitable alike by aquatic or terrestrial animals.

CHAPTER XXVIII.

EARTHQUAKES AND THEIR EFFECTS.

EARTHQUAKES AND THEIR EFFECTS—DEFICIENCY OF ANCIENT ACCOUNTS—ORDINARY ATMOSPHERIC PHENOMENA—CHANGES PRODUCED BY EARTHQUAKES IN MODERN TIMES CONSIDERED IN CHRONOLOGICAL ORDER—EARTHQUAKE IN NEW ZEALAND—PERMANENT UPHEAVAL AND SUBSIDENCE OF LAND—A FAULT PRODUCED IN THE ROCKS—EARTHQUAKE IN SYRIA, 1837—EARTHQUAKES IN CHILI IN 1837 AND 1835—ISLE OF SANTA MARIA RAISED TEN FEET—CHILI, 1822—EXTENT OF COUNTRY ELEVATED—EARTHQUAKE OF CUTCH IN 1819—SUBSIDENCE IN THE DELTA OF THE INDUS—ISLAND OF SUMBAWA IN 1815—EARTHQUAKE OF CARACCAS IN 1812—SHOCKS IN THE VALLEY OF THE MISSISSIPPI AT NEW MADRID IN 1811.

In the sketch given in Chapter XXIII. of the geographical boundaries of volcanic regions, I stated, that although the points of eruption are but thinly scattered, constituting mere spots on the surface of those vast districts, yet the subterranean movements extend simultaneously over immense areas. We may now proceed to consider the changes which these movements produce on the surface, and in the internal structure of the earth's crust.

Deficiency of ancient accounts.—It is only within the last two centuries, since Hooke first promulgated, in 1688, his views respecting the connection between geological phenomena and earthquakes, that the permanent changes effected by these convulsions have excited attention. Before that time, the narrative of the historian was almost exclusively confined to the number of human beings who perished, the number of cities laid in ruins, the value of property destroyed, or certain atmospheric appearances which dazzled or terrified the observers. The creation of a new lake, the engulphing of a city, or the raising of a new island, are sometimes, it is true, adverted to, as being too obvious, or of too much geographical or political interest to be passed over in silence. But no

researches were made expressly with a view of ascertaining the amount of depression or elevation of the ground, or any particular alterations in the relative position of sea and land; and very little distinction was made between the raising of soil by volcanic ejections, and the upheaving of it by forces acting from below. The same remark applies to a very large proportion of modern accounts: and how much reason we have to regret this deficiency of information appears from this, that in every instance where a spirit of scientific enquiry has animated the eye-witnesses of these events, facts calculated to throw light on former modifications of the earth's structure are recorded.

Phenomena attending earthquakes.—As I shall confine myself almost entirely, in the following notice of earthquakes, to the changes brought about by them in the configuration of the earth's crust, I may mention, generally, some accompaniments of these terrible events which are almost uniformly commemorated in history, so that it may be unnecessary to advert to them again. Irregularities in the seasons preceding or following the shocks; sudden gusts of wind, interrupted by dead calms; violent rains at unusual seasons, or in countries where, as a rule, they are almost unknown; a reddening of the sun's disk, and haziness in the air, often continued for months; an evolution of electric matter, or of inflammable gas from the soil, with sulphurous and mephitic vapours; noises underground, like the running of carriages, or the discharge of artillery, or distant thunder; animals uttering cries of distress, and evincing extraordinary alarm, being more sensitive than men to the slightest movement; a sensation like sea-sickness, and a dizziness in the head, experienced by men:—these, and other phenomena, less connected with our present subject as geologists, have recurred again and again at distant ages, and in all parts of the globe.

I shall now begin the enumeration of earthquakes with the latest authentic narratives, and so carry back the survey retrospectively, that I may bring before the reader, in the first place, the minute and circumstantial details of modern times, and thus enable him, by observing the extraordinary

amount of change within the last 170 years, to perceive how great must be the deficiency in the meagre annals of earlier eras.

EARTHQUAKES OF THE NINETEENTH CENTURY.*

New Zealand, 1855.—*Permanent upheaval and subsidence of land.*—In no country, perhaps, where the English language is spoken, have earthquakes, or, to speak more correctly, the subterranean causes to which such movements are due, been so active in producing changes of geological interest as in New Zealand. The convulsions which have agitated this archipelago since it was first known to whalers or settlers, have visited different districts in succession.

The Rev. R. Taylor, many years a missionary in New Zealand, states that the shocks of 1826, 1841, and 1843 expended each of them their chief violence in distinct areas. In the year 1823, there was a small cove called the Jail, about 80 miles north of Dusky Bay, much visited by sealers, for it afforded suitable anchorage for their vessels, being sheltered by lofty cliffs, and having deep water so close to the shore that they could step out of their boats on to the rocks.

After a succession of earthquakes in 1826 and 1827, so complete was the transformation of this coast that its former features could no longer be recognised; the cove had become dry land, and trees were seen under water near the coast, having probably been carried down by landslips into what

* Since the publication of the first edition of this work, numerous accounts of recent earthquakes have been published; but as they do not illustrate any new principle, I cannot insert them, as they would enlarge too much the size of my work. The late Von Hoff published from time to time, in Poggendorf's Annalen, lists of earthquakes which happened between 1821 and 1836; and, by consulting these, the reader will perceive that every month is signalised by one or many convulsions in some part of the globe. See also Mallet's Dynamics of Earthquakes, Trans. Roy. Irish Acad. 1846; also Art. 'Earthquakes,' Admiralty Manual, 1849; also Mr. Mallet's reports on earthquakes to Brit. Assoc. 1850, 1852, and 1858, containing a complete catalogue of known earthquakes from 1606 B.C. to A.D. 1842; also remarks on the earthquakes of which accounts were published since that time by Prof. Alexis Perrey, of Dijon. A continued series of accounts of earthquakes and volcanic eruptions by the last-mentioned author, drawn up with great care, since 1842, has been published by the Royal Academy of Belgium, with the discussion of their causes and effect. See also Hopkins' Report, Brit. Assoc. 1847–8.

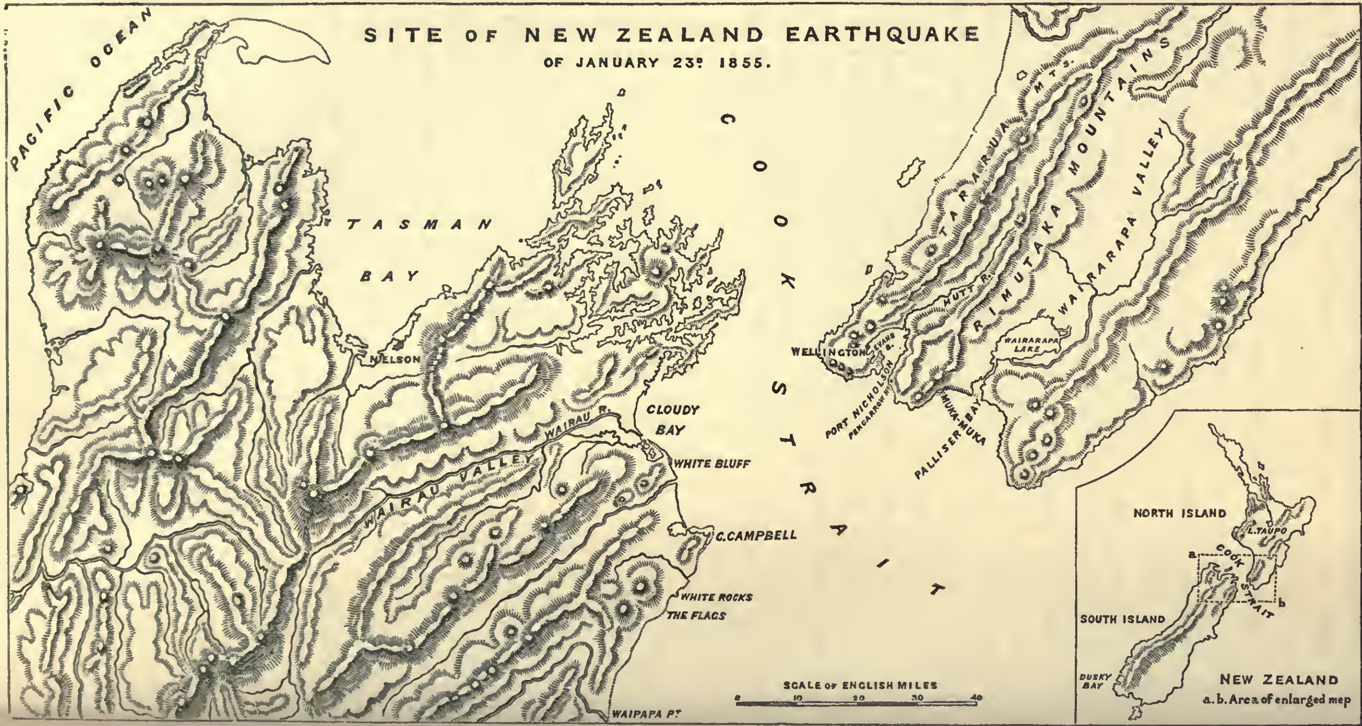
was previously deep water, for large masses are said to have slid down from the hills into the sea. The same writer informs us that in 1847, the hull of a vessel was discovered on the western coast of the South Island. It was lying 200 yards inland, and was supposed to be the 'Active,' which was lost in 1814. A small tree was growing through its bottom, and Mr. Taylor suggests that the coast had risen, so as to cause the ocean to retire to a distance of 200 yards from the old shore line, where the vessel had been stranded; but a more precise investigation of the locality will be required before we can feel sure that the vessel was not carried in by a wave raised during the earthquake, for such waves have, in modern times, left much larger ships high and dry in the interior of Peru and some other countries.* (See p. 157.) The natives are said to have told our first settlers that they might expect a great earthquake every seven years; and although such exact periodicity has by no means been verified, the average number of violent shocks in a quarter of a century seems not to have fallen short of the estimate here referred to.

In the course of the year 1856, I had an opportunity of conversing in London with three gentlemen, all well qualified as scientific observers, who were eye-witnesses of the tremendous earthquake experienced in January of the preceding year in New Zealand. These were, Mr. Edward Roberts, of the Royal Engineers department; Mr. Walter Mantell, son of the celebrated geologist; and Mr. Frederick A. Weld, a landed proprietor in the South Island.† The earthquake occurred in the night of January 23, 1855, and was most violent in the narrowest part of Cook Strait, a few miles to the S.E. of Port Nicholson (see Map, fig. 107, p. 84); but the shocks were felt by ships at sea 150 miles from the coast, and the whole area shaken of land and water is estimated at 360,000 square miles, an area three times as large as the British Isles. In the vicinity of Wellington, in the North Island, a tract of land comprising 4,600 square miles

* Rev. R. Taylor, 'New Zealand and its Inhabitants,' London, 1855.

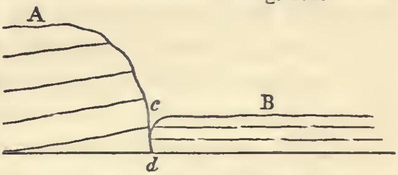
† This account was published by me in the Bulletin de la Soc. Géol. de France, 1856, p. 661.

Fig. 107.


SITE OF NEW ZEALAND EARTHQUAKE
OF JANUARY 23º 1855.
PACIFIC OCEAN
TASMAN
BAY
NELSON
COOK STRAIT
CLOUDY
BAY
WAIRAU R.
WAIRAU VALLEY
WHITE BLUFF
C. CAMPBELL
WHITE ROCKS
THE FLAGS
WAIPAPA PT
WELLINGTON
PORT NICHOLSON
HUTT R.
TARARUA MTS.
RIMUTAKA MOUNTAINS
WAIRARAPA VALLEY
WAIRARAPA LAKE
PALLISER BAY
MUKA-MUKA
SCALE OF ENGLISH MILES
10
20
30
40
NORTH ISLAND
L. TAUPO
SOUTH ISLAND
DUSKY BAY
NEW ZEALAND
a. b. Area of enlarged map

(not much inferior to Yorkshire in dimensions), is supposed by Mr. Roberts to have been permanently upraised from 1 to 9 feet. There was no perceptible elevation on the coast 16 miles N. of Wellington, but from that point to Pencarrow Head, on the east side, at the entrance of Port Nicholson (see Map, fig. 107), the amount of upheaval went on increasing, somewhat gradually, till it reached a vertical height of 9 feet along the eastern flank of the Remutaka Mountains. This range terminates in Cook Strait, between Port Nicholson and Palliser Bay, in a lofty coast rising rapidly to heights about 4,000 feet above the sea. Here the vertical movement ceased abruptly along the base of these hills, not affecting the low country to the eastward, B, fig. 108, called the Plain of Wairarapa. The points of minimum and maximum elevation from N.W. to S.E., in the district above alluded to, are about 23 miles apart, which therefore express the breadth of the upraised area. Mr. Roberts was employed professionally, before and after January 23, in executing several government works in the harbour of Port Nicholson and on the coast, and had occasion to observe minutely the changes in the level of the land, which took place at various points, and especially in the sea-cliff, called Muka-Muka, 12 miles S.E. of Wellington, where the eastern flank of the Remutaka range, before described, terminates southwards in Cook Strait. Here a distinct line of fault, *c*, *d*, fig. 108, was observed, the rocks on one side A, being raised vertically 9 feet, while the strata B, on the other side of the fissure *c*, *d*, experienced no movement. The uplifted mass A consists, according to Mr. Walter Mantell, of argillite, having the ordinary composition of clay slate, but not laminated. It presents a cliff, several hundred feet high towards the straits, whereas

Fig. 108.



Junction of argillite and tertiary strata at Muka-Muka cliff.*

A. Argillite. B. Tertiary strata. *c*, *d*. Line of vertical fissure and fault.

* I give this section from the description of my informants, and it must therefore be simply regarded as an explanatory diagram.

the horizontally stratified tertiary strata exposed to the eastward form a comparatively low cliff, not exceeding 80 feet in height. These tertiary strata, which are of marine origin, did not, as already stated, participate in the upward movement. Mr. Roberts was able to measure accurately the amount of permanent upheaval in the older formation, by observing the altered position of a white band of nullipores, with which the surface of the rock below the level of low tide had been coated. This white zone, a few hours after the earthquake, was found to be 9 feet above its former level. Previously to the shock, there had been no room to pass between the sea and the base of the perpendicular cliff called Muka-Muka, except for a short time at low water, and as the herdsmen were obliged to wait for low tide in order to drive their cattle past the cliff, Mr. Roberts was engaged in constructing a road there. But immediately after the upheaval, a gently sloping raised beach, more than 100 feet wide, was laid dry, affording ample space at all states of the tide for the passage of man and beast.

The junction of the older and newer rocks along the line of fault above described is marked in the interior of the country by a continuous escarpment running north and south along the base of the Remutaka Mountains, where the older rocks present a steep slope towards the east, or towards the great plain of the Wairarapa formed of the modern tertiary deposit before mentioned. The course of the fault along the base of the escarpment was rendered visible by a nearly perpendicular cliff of fresh aspect 9 feet in height and traceable in an inland direction to the extraordinary distance of about 90 miles, according to information given by Mr. Borlase, a settler who lived in the Wairarapa valley about 60 miles north of Cook Strait. It was marked, moreover, in many places by an open fissure into which cattle fell and could not in some cases be recovered, or by fissures from 6 to 9 feet broad, filled here and there with soft mud and loose earth. At the same time that this vertical movement took place on January 23, the harbour of Port Nicholson, about 12 miles to the westward of Muka-Muka cliff, together with the valley of the Hutt, was raised from 4 to 5 feet, the greater elevation

being on the eastern, and the lesser on the western side of the harbour. A rock called the Balley Rock, a short distance from Evans Bay, was formerly 2 feet under water at the lowest tides, and a vessel having touched upon it, a buoy had been placed over it to mark its position. This rock projected after the shock nearly 3 feet above the surface of the water at low tide. The rise of the tide in the Hutt river was sensibly diminished by the earthquake. At the time of the convulsion great waves of the sea rolled in upon the coast, and for several weeks the tides were very irregular. Dead fish were left by a wave on the racecourse at Wellington, and Mr. Mantell states that others were also met with by several vessels in Cook Strait floating on the sea in surprising numbers, some of them of species never seen before by the fishermen.

Mr. Weld, who resided south of the Straits in the South Island, informed me that, besides experiencing there the shock of the 23rd, he felt another next morning of equal violence, and waves of the sea rolled in along the coast for a distance of 50 miles. At a place called the Flags, between Cape Campbell and Waipapa (see Map), some men were loading a vessel with wood, when they saw distinctly an earthquake approaching them from a point called 'the White Rocks,' 3 miles to the northward. Its approach was rendered visible by the rolling of stones from the top of the cliffs, also by landslips and clouds of dust, and by the accompanying sea wave. Upon the whole it appears that the area convulsed in the South Island was not so extensive as that upheaved around Wellington, also that to the south of the Straits the direction of the movement was reversed, being for the most part a downward one. The valley of the Wairau, with parts of the adjoining coast, subsided about 5 feet, so that the tide flowed several miles farther up into the Wairau River than it formerly did, and ships taking in fresh water were obliged to go three miles farther up the river to obtain a supply, than they did before the earthquake.

There was no volcanic eruption, whether in the Northern or Southern Island, at the time of these events; but the natives allege that the temperature of the Taupo hot springs

(see small Map, p. 84) was sensibly elevated, just before the catastrophe.

I will now conclude this sketch of the changes produced in 1855 by observing that a question arose as to whether in the region about Port Nicholson the land, after it was upheaved several feet in January, sank again to some slight extent or a few inches in the course of 7 or 8 months, or before September 1855. When Mr. Roberts left New Zealand, three months after the earthquake, there had been no sinking of the upraised land, and he felt persuaded that he could not have failed to notice even a slight change of level had any occurred. He ascertained ten weeks after the shock that there had certainly been no subsidence whatever on the coast at Pencarrow Head, and the tides were so irregular long after the earthquake, in the harbour of Port Nicholson and elsewhere, that the supposed partial sinking of the coast which some believed to have taken place might perhaps be deceptive. It is surprising how soon the signs of a recent change of level on a coast are effaced to all eyes but those of the scientific observer, especially where there is a rise and fall of the tides. Rocks newly exposed soon begin to weather, and vegetation spreads over the emerged land, and a new beach, with all the characters of the old one, is formed in a few months along the sea-margin.

The geologist has rarely enjoyed so good an opportunity as that afforded him by this convulsion in New Zealand, of observing one of the steps by which those great displacements of the rocks called 'faults' may in the course of ages be brought about. The manner also in which the upward movement increased from north-west to south-east explains the manner in which beds may be made to dip more and more in a given direction by each successive shock.

An independent witness of the earthquake of January 1855, a civil engineer, says in a letter to Mr. Robert Mallet that 'the first and greatest shock of January 23 lasted about a minute and a half. All the brick buildings in Wellington were overthrown, as well as the bridge over the Hutt. The hillsides opposite Wellington, those of the Remutaka range, were much shaken, as evidenced by the many bare patches with which

they were chequered, fully to the extent of one-third of their surface, whence trees had been shaken off.' The ground in this range, he says, was more violently shaken than in Wellington, and the direction of the shock was N.E. and S.W., agreeing with that of the chain of hills. After the shock the tide did not come at high water within 3 or 4 feet of its former height.*

Mr. Weld was in the South Island during the previous earthquake of 1848, and he informed me that a great rent was then caused in a chain of mountains varying in height from 1,000 to 4,000 feet, which run southwards from the White Bluff in Cloudy Bay and may be considered a prolongation of the Remutaka or Tararua chain above alluded to. (See Map, p. 84.) This fissure of 1848 was not more than 18 inches in average width, but was remarkable for its length, for it was partly traced by Mr. Weld, and partly by observers on whom he could rely, for 60 miles, striking north-north-east and south-south-west in a line parallel to the axis of the chain.

Syria, January, 1837.—It has been remarked that earthquakes affect elongated areas. The violent shock which devastated Syria in 1837 was felt on a line 500 miles in length by 90 in breadth: † more than 6,000 persons perished; deep rents were caused in solid rocks, and new hot springs burst out at Tabereah.

Chili—Valdivia, 1837.—One of the earthquakes by which in the present century the position of land is known to have been permanently altered is that which occurred in Chili, on November 7, 1837. On that day Valdivia was destroyed, and a whaler, commanded by Captain Coste, was violently shaken at sea, and lost her masts, in lat. 43° 38′ S., in sight of the land. On the following 11th of December the captain went to a spot near the island of Lemus, one of the Chonos archipelago, where he had anchored two years before, and he there found that the bottom of the sea had been raised more than 8 feet. Some rocks formerly covered at all times by the sea were now constantly exposed, and an enormous quantity of shells and fish in a decaying state, which had been thrown

* Reports of Brit. Assoc. 1858, p. 105.

† Darwin, Geol. Proceedings, vol. ii. p. 658.

there by the waves, or suddenly laid dry during the earthquake, attested the recent date of the occurrence. The whole coast was strewn with uprooted trees.*

Chili—Conception, 1835.—Fortunately we have a still more detailed account of the geographical changes produced in the same country on February 20, 1835. An earthquake was then felt at all places between Copiapo and Chiloe, nearly 1,000 miles from north to south, and from Mendoza to Juan Fernandez, about 500 miles from east to west. 'Vessels,' says Mr. Caldcleugh, 'navigating the Pacific, within 100 miles of the coast, experienced the shock with considerable force.' † Conception, Talcahuano, Chillan, and other towns, were thrown down. From the account of Captain Fitz Roy, R.N., who was then employed in surveying the coast, we learn that after the shock the sea retired in the Bay of Conception, and the vessels grounded, even those which had been lying in seven fathoms water: all the shoals were visible, and soon afterwards a wave rushed in and then retreated, and was followed by two other waves. The vertical height of these waves does not appear to have been much greater than 16 or 20 feet, although they rose to much greater heights when they broke upon a sloping beach.

According to Mr. Caldcleugh and Mr. Darwin, the whole volcanic chain of the Chilian Andes, a range 1,300 miles in length, was in a state of unusual activity, both during the shocks and for some time preceding and after the convulsion, and lava was seen to flow from the crater of Osorno. (See Map, fig. 109.) The island of Juan Fernandez, distant 365 geographical miles from Chili, was violently shaken at the same time, and devastated by a great wave. A submarine volcano broke out there near Bacalao Head, about a mile from the shore, in 69 fathoms water, and illumined the whole island during the night.‡

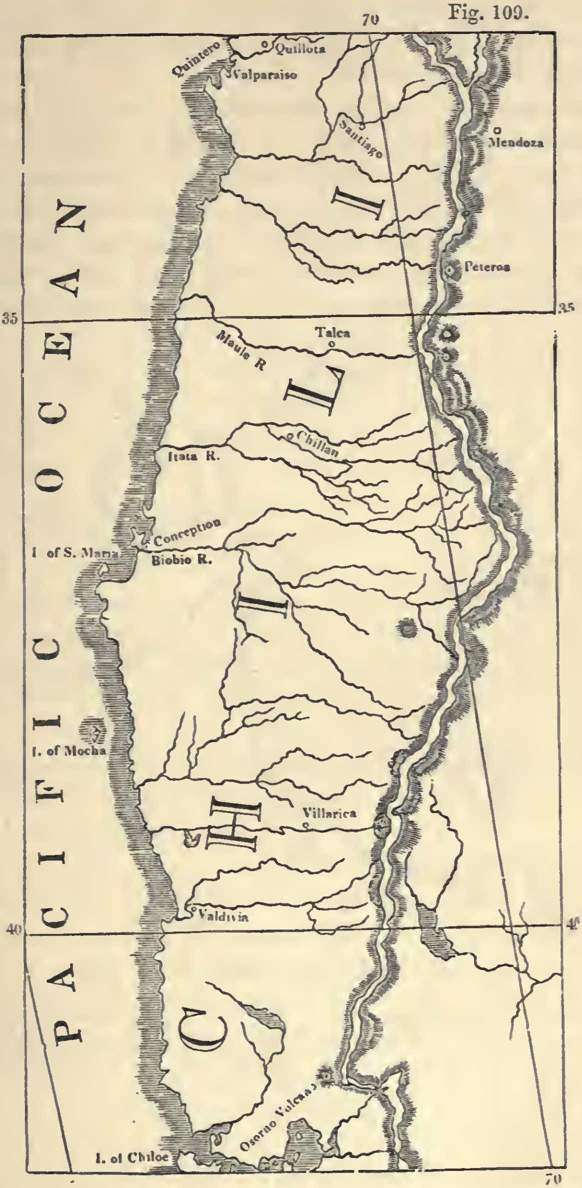
'At Conception,' says Captain Fitz Roy, 'the earth opened and closed rapidly in numerous places. The direction of the cracks was not uniform, though generally from south-east to

* Dumoulin, Comptes Rendus de l'Acad. des Sci. Oct. 1838, p. 706.

† Phil. Trans. 1836, p. 21.

‡ Ibid. 1826.

Fig. 109.



north-west. The earth was not quiet for three days after the great shock, and more than 300 shocks were counted between February 20 and March 4. The loose earth of the valley of

the Biobio was everywhere parted from the solid rocks which bound the plain, there being an opening between them from an inch to a foot in width.

'For some days after February 20, the sea at Talcahuano,' says Captain Fitz Roy, 'did not rise to the usual marks by 4 or 5 feet vertically. When walking on the shore, even at high water, beds of dead mussels, numerous chitons, and limpets, and withered sea-weed, still adhering, though lifeless, to the rocks on which they had lived, everywhere met the eye.' But this difference in the relative level of the land

Fig. 110.

Part of Chili altered by Earthquake of February, 1835.

and sea gradually diminished, till in the middle of April the water rose again to within 2 feet of the former high-water mark. It might be supposed that these changes of level merely indicated a temporary disturbance in the set of the currents, or in the height of the tides at Talcahuano; but, on considering what occurred in the neighbouring island of Santa Maria, Captain Fitz Roy concluded the land had been raised 4 or 5 feet in February, and that it had returned in April to within 2 or 3 feet of its former level.

Santa Maria, the island just alluded to, is about 7 miles long and 2 broad, and about 25 miles south-west of Conception. (See Map, p. 92.) The phenomena observed there are most important. 'It appeared,' says Captain Fitz Roy, who visited Santa Maria twice, the first time at the end of March, and afterwards in the beginning of April, 'that the southern extremity of the island had been raised 8 feet, the middle 9, and the northern end upwards of 10 feet. On steep rocks, where vertical measurements could be correctly taken, beds of dead mussels were found 10 feet above high-water mark.

'An extensive rocky flat lies around the northern parts of Santa Maria. Before the earthquake this flat was covered by the sea, some projecting rocks only showing themselves. Now, the whole flat is exposed, and square acres of it are covered with dead shell-fish, the stench arising from which is abominable. By this elevation of the land the southern port of Santa Maria has been almost destroyed; little shelter remaining there, and very bad landing.' The surrounding sea is also stated to have become shallower in exactly the same proportion as the land had risen; the soundings having diminished a fathom and a half everywhere around the island.

At Tubal, also, to the south-east of Santa Maria, the land was raised 6 feet, at Mocha 2 feet, but no elevation could be ascertained at Valdivia.

Among other effects of the catastrophe, it is stated that cattle standing on a steep slope, near the shore, were rolled down into the sea, and many others were washed off by the great wave from low land and drowned.*

In November of the same year (1835), Conception was shaken by a severe earthquake, and on the same day Osorno, at the distance of 400 miles, renewed its activity. These facts prove not only the connection of earthquakes with volcanic eruptions in this region, but also the vast extent of the subterranean areas over which the disturbing cause acts simultaneously.

Bay of Naples—Ischia, 1828.—On February 2, the whole

* Darwin's Journ. of Travels in South America, Voyage of 'Beagle,' p. 372.

island of Ischia was shaken by an earthquake, and in the October following I found all the houses in Casamicciol still without their roofs. On the sides of a ravine between that town and Forio, I saw masses of greenish tuff which had been thrown down. The hot-spring of Rita, which was nearest the centre of the movement, was ascertained by M. Covelli to have increased in temperature, showing, as he observes, that the explosion took place below the reservoirs which heat the thermal waters.*

Bogota, 1827.—On November 16, 1827, the plain of Bogota, in New Granada, or Colombia, was convulsed by an earthquake, and a great number of towns were thrown down. Torrents of rain swelled the Magdalena, sweeping along vast quantities of mud and other substances, which emitted a sulphurous vapour and destroyed the fish. Popayan, which is distant 200 geographical miles S.S.W. of Bogota, suffered greatly. Wide crevices appeared in the road of Guanacas, leaving no doubt that the whole of the Cordilleras sustained a powerful shock. Other fissures opened near Costa, in the plains of Bogota, into which the river Tunza immediately began to flow.† Extraordinary rains accompanied the shocks before mentioned; and two volcanos are said to have been in eruption in the mountain-chain nearest to Bogota.

Chili, 1822.—On November 19, 1822, the coast of Chili was visited by a most destructive earthquake. The shock was felt simultaneously throughout a space of 1,200 miles from north to south. St. Jago, Valparaiso, and some other places were greatly injured. When the district round Valparaiso was examined on the morning after the shock, it was found that the coast for a considerable distance was raised above its former level.‡ At Valparaiso, the elevation was 3 feet, and at Quintero about 4 feet. Part of the bed of the sea, says Mrs. Graham, remained bare and dry at high water, 'with beds of oysters, mussels, and other shells adhering to the rocks on which they grew, the fish being all dead, and exhaling most offensive effluvia.' §

* Biblioth. Univ. Oct. 1828, p. 175.

† Phil. Mag. July, 1828, p. 37.

‡ Geol. Trans. vol. i. 2nd ser., and Journ. of Sci. 1824, vol. xvii. p. 40.

§ Geol. Trans. vol. i. 2nd ser. p. 415.

An old wreck of a ship, which before could not be approached, became accessible from the land, although its distance from the original sea-shore had not altered. It was observed that the watercourse of a mill, at the distance of about a mile from the sea, gained a fall of 14 inches in little more than 100 yards; and from this fact it is inferred that the rise in some parts of the inland country was far more considerable than on the borders of the ocean.* Part of the coast thus elevated consisted of granite, in which parallel fissures were caused, some of which were traced for a mile and a half inland. Cones of earth about 4 feet high were thrown up in several districts, by the forcing up of water mixed with sand through funnel-shaped hollows,—a phenomenon very common in Calabria, and the explanation of which will hereafter be considered. Those houses in Chili of which the foundations were on rock, were less damaged than such as were built on alluvial soil.

Mr. Cruickshanks, an English botanist, who resided in the country during the earthquake, has informed me that some rocks of greenstone at Quintero, a few hundred yards from the beach, which had always been under water till the shock of 1822, have since been uncovered when the tide is at half-ebb; and he states that, after the earthquake, it was the general belief of the fishermen and inhabitants of the Chilian coast, *not* that the land had risen, but that the ocean had permanently retreated.

Dr. Meyen, a Prussian traveller, who visited Valparaiso in 1831, says that on examining the rocks both north and south of the town nine years after the event, he found, in corroboration of Mrs. Graham's account, that remains of animals, and sea-weed, the *Lessonia* of Bory de St. Vincent, which has a firm ligneous stem, still adhered to those rocks which in 1822 had been elevated above high-water mark.† According to the same author, the whole coast of Central Chili was raised about 4 feet, and banks of marine shells were laid dry on many parts of the coast. He observed similar banks, elevated at unknown periods, in several places, especially at

* Journ. of Sci. vol. xvii. p. 42.

† Reise um die Erde; and see Dr. Meyen's letter cited Foreign Quart. Rev. No. 33, p. 13, 1836.

Copiapo, where the species all agree with those now living in the ocean. Mr. Freyer also, who resided some years in South America, has confirmed these statements;* and Mr. Darwin obtained evidence that the remains of an ancient wall, formerly washed by the sea, and now 11½ feet above high-water mark, acquired several feet of this elevation during the earthquake of 1822.†

The shocks continued up to the end of September 1823; even then, 48 hours seldom passed without one, and sometimes two or three were felt during 24 hours. Mrs. Graham observed, after the earthquake of 1822, that besides a beach newly raised above high-water mark, there were several older elevated lines of beach, one above the other, consisting of shingle mixed with shells extending in a parallel direction to the shore, to the height of 50 feet above the sea.‡

Extent of country elevated.—By some observers it has been supposed that the whole country from the foot of the Andes to a great distance under the sea was upraised in 1822, the greatest rise being at the distance of about 2 miles from the shore. 'The rise upon the coast was from 2 to 4 feet:—at the distance of a mile inland it must have been from 5 to 6 or 7 feet.' § It has also been conjectured by the same eye-witnesses to the convulsion, that the area over which this permanent alteration of level extended may have been equal to 100,000 square miles. Although the increased fall of certain watercourses may have afforded some ground for this conjecture, it must be considered as very hypothetical, and the estimate may have exceeded or greatly fallen short of the truth. It may nevertheless be useful to reflect on the enormous amount of change which this single convulsion occasioned, if the extent of country moved upward really amounted to 100,000 square miles,—an extent just equal to half the area of France, or about five-sixths of an area of Great Britain and Ireland. If we suppose the elevation to have been only 3 feet on an average, it will be seen that the mass of rock added to the continent of America by the move-

* Proc. Geol. Soc. No. xl. p. 179, Feb. 1835.

† Proc. Geol. Soc. vol. ii. p. 447.

‡ Trans. Geol. Soc. vol. i. 2nd ser., p. 415.

§ Journal of Science, vol. xvii. pp. 40, 45.

ment, or, in other words, the mass previously below the level of the sea, and after the shocks permanently above it, must have contained 57 cubic miles in bulk; which would be sufficient to form a conical mountain 2 miles high (or about as high as Etna), with a circumference at the base of nearly 33 miles. We may take the mean specific gravity of the rock at 2·655,—a fair average, and a convenient one in such computations, because at such a rate a cubic yard weighs 2 tons. Then, assuming the Great Pyramid of Egypt, if solid, to weigh, in accordance with an estimate before given, 6,000,000 tons, we may state the rock added to the continent by the Chilian earthquake to have more than equalled 100,000 Pyramids.

But it must always be borne in mind that the weight of rock here alluded to constituted but an insignificant part of the whole amount which the volcanic forces had to overcome. The thickness of rock between the surface of Chili and the subterranean foci of volcanic action may be many miles or leagues deep. Say that the thickness was only 2 miles, even then the mass which changed place and rose 3 feet, being 200,000 cubic miles in volume, must have exceeded in weight 363,000,000 Pyramids.

It may be instructive to consider these results in connection with others already obtained from a different source, and to compare the working of two antagonist forces—the levelling power of running water, and the expansive energy of subterranean heat. How long, it may be asked, would the Ganges require, according to data before explained from observations made 500 miles up the river, at Ghazepoor (Vol. I. p. 479), to transport to the sea a quantity of solid matter equal to that which may have been added to the land by the Chilian earthquake? The discharge of mud in one year by the Ganges at its mouth (see Vol. I. p. 481) was estimated at 20,000,000,000 cubic feet. According to that estimate it would require about 4 centuries (or 418 years) before the river could bear down from the continent into the sea a mass equal to that gained by the Chilian earthquake. In about half that time, perhaps, the united waters of the Ganges and Burrampooter might accomplish the operation.

Earthquake of Cutch, 1819.—A violent earthquake occurred at Cutch, in the delta of the Indus, on June 16, 1819. (See Map, Fig. 111.) The principal town, Bhooj, was converted into a heap of ruins, and its stone buildings were thrown down. The movement was felt over an area having a radius of 1,000 miles from Bhooj, and extending to Khatmandoo, Calcutta, and Pondicherry.* The vibrations were felt in North-West India, at a distance of 800 miles, after an interval of about 15 minutes after the earthquake at Bhooj. At Ahmedabad the great mosque, erected by Sultan Ahmed nearly 450 years

Fig. 111.

before, fell to the ground, attesting how long a period had elapsed since a shock of similar violence had visited that point. At Anjar, the fort, with its tower and guns, were hurled to the ground in one common mass of ruin. The shocks continued until the 20th; when, 30 miles north-west from Bhooj, the volcano called Denodur is said by some to

* See Asiatic Journal, vol. i.

have sent forth flames, but Captain Grant, when in Cutch in 1838, was unable to authenticate this statement.

Although the ruin of towns was great, the face of nature in the inland country, says Captain (General) Macmurdo, was not visibly altered. In the hills some large masses only of rock and soil were detached from the precipices; but the eastern and almost deserted channel of the Indus, which bounds the province of Cutch, was greatly changed. This estuary, or inlet of the sea, was, before the earthquake, fordable at Luckput, being only about 1 foot deep when the tide was at ebb, and at flood tide never more than 6 feet; but it was deepened at the fort of Luckput, after the shock, to more than 18 *feet at low water*.* On sounding other parts of the channel, it was found, that where previously the depth of the water at flood never exceeded 1 or 2 feet, it had become from 4 to 10 feet deep. By these and other remarkable changes of level, a part of the inland navigation of that country, which had been closed for centuries, became again practicable.

Fort and village submerged.—The fort and village of Sindree, on the eastern arm of the Indus, above Luckput, are stated by the same writer to have been overflowed; and, after the shock, the tops of the houses and wall were alone to be seen above the water, for the houses, although submerged, were not cast down (see fig. 113, p. 102). Had they been situated, therefore, in the interior, where so many forts were levelled to the ground, their site would, perhaps, have been regarded as having remained comparatively unmoved. Hence we may suspect that great permanent upheavings and depressions of soil may be the result of earthquakes, without the inhabitants being in the least degree conscious of any change of level.

A more recent survey of Cutch, by Sir A. Burnes, who was not in communication with Captain Macmurdo, confirms the facts above enumerated, and adds many important details.† That officer examined the delta of the Indus in 1826 and 1828, and from his account it appears that, when Sindree subsided in June 1819, the sea flowed in by the eastern

* Macmurdo, Ed. Phil. Journ. iv. 106.

† This memoir is now in the Library of the Royal Asiatic Society of London.

mouth of the Indus, and in a few hours converted a tract of land, 2,000 square miles in area, into an inland sea, or lagoon. Neither the rush of the sea into this new depression, nor the movement of the earthquake, threw down entirely the small fort of Sindree, one of the four towers, the north-western, still continuing to stand; and, the day after the earthquake,

Fig. 112.

Fort of Sindree, on the eastern branch of the Indus, before it was submerged by the earthquake of 1819, from a sketch by Capt. Grindlay, made in 1808.*

the inhabitants, who had ascended to the top of this tower, saved themselves in boats.†

Elevation of the Ullah Bund.—Immediately after the shock, the inhabitants of Sindree saw at the distance of 5½ miles from their village, a long elevated mound, where previously there had been a low and perfectly level plain. (See Map, p. 98.) To this uplifted tract they gave the name of 'Ullah Bund,' or the 'Mound of God,' to distinguish it from several artificial dams previously thrown across the eastern arm of the Indus.

* I was indebted to my friend the late Sir Alexander Burnes for the accompanying sketch (fig. 112) of the fort of Sindree, as it appeared eleven years before the earthquake.

† Several particulars not given in the earlier edition were afterwards obtained by me from personal communication with Sir A. Burnes in London.

Extent of country raised.—It has been ascertained that this new-raised country is *upwards of fifty miles* in length from east to west, running parallel to that line of subsidence before mentioned which caused the grounds around Sindree to be flooded. The range of this elevation extends from Puchum Island towards Gharee; its breadth from north to south is conjectured to be in some parts *sixteen miles*, and its greatest ascertained height above the original level of the delta is 10 feet,—an elevation which appears to the eye to be very uniform throughout.

For several years after the convulsion of 1819, the course of the Indus was very unsettled, and at length, in 1826, the river threw a vast body of water into its eastern arm, that called the Phurraun, above Sindree; and forcing its way in a more direct course to the sea, burst through all the artificial dams which had been thrown across its channel, and at length cut right through the 'Ullah Bund,' whereby a natural section was obtained. In the perpendicular cliffs thus laid open Sir A. Burnes found that the upraised lands consisted of clay filled with shells. The new channel of the river where it intersected the 'bund' was 18 feet deep, and 40 yards in width; but in 1828 the channel was still farther enlarged. The Indus, when it first opened this new passage, threw such a body of water into the new mere, or salt lagoon, of Sindree, that it became fresh for many months; but it had recovered its saltness in 1828, when the supply of river-water was less copious, and finally it became more salt than the sea, in consequence, as the natives suggested to Sir A. Burnes, of the saline particles with which the 'Runn of Cutch' is impregnated.

In 1828 Sir A. Burnes went in a boat to the ruins of Sindree, where a single remaining tower was seen in the midst of a wide expanse of sea. The tops of the ruined walls still rose 2 or 3 feet above the level of the water; and standing on one of these, he could behold nothing in the horizon but water, except in one direction, where a blue streak of land to the north indicated the Ullah Bund. This scene presents to the imagination a lively picture of the revolutions now in progress on the earth—a waste of waters where

a few years before all was land, and the only land visible consisting of ground uplifted by a recent earthquake.

Ten years after the visit of Sir A. Burnes above alluded to, my friend Captain Grant, F.G.S., of the Bombay Engineers, had the kindness to send at my request a native surveyor to make a plan of Sindree and the Ullah Bund, in March, 1838. From his description it appears that, at that season, the driest of the whole year, he found the channel traversing the Bund to be 100 yards wide, without water, and encrusted with salt. He was told that it has now only 4 or 5 feet of water in it after rains. The sides or banks were nearly perpendicular, and 9 feet in height. The lagoon has

Fig. 113.

View of the Fort of Sindree, from the west, in March, 1838.

diminished both in area and depth, and part near the fort was dry land. The annexed drawing, made by Captain Grant from the surveyor's plan, shows the appearance of the fort in the midst of the lake, as seen in 1838 from the west, or from the same point as that from which Captain Grindlay's sketch (see fig. 112) was taken in 1808, before the earthquake.

The Runn of Cutch is a flat region of a very peculiar character, and no less than 7,000 square miles in area: a greater superficial extent than Yorkshire, or about one-fourth the area of Ireland. It is not a desert of moving sand, nor a marsh, but evidently the dried-up bed of an inland sea, which for a great part of every year has a hard and dry bottom without vegetation or only supporting here and

there a few tamarisks. But during the monsoons, when the sea runs high, the salt water driven up from the Gulf of Cutch and the creeks at Luckput overflows a large part of the Runn, especially after rains, when the soaked ground permits the sea-water to spread rapidly. The Runn is also liable to be overflowed occasionally in some parts by river-water: and it is remarkable that the only portion which was ever highly cultivated (that anciently called Sayra) is now permanently submerged. The surface of the Runn is sometimes encrusted with salt about an inch in depth, in consequence of the evaporation of the sea-water. Islands rise up in some parts of the waste, and the boundary lands form bays and promontories. The natives have various traditions respecting the former separation of Cutch and Sinde by a bay of the sea, and the drying up of the district called the Runn. But these tales, besides the usual uncertainty of oral tradition, are farther obscured by mythological fictions. The conversion of the Runn into land is chiefly ascribed to the miraculous powers of a Hindoo saint by name Damorath (or Dhoorunnath), who had previously done penance for twelve years on the summit of Denodur hill. Captain Grant infers, on various grounds, that this saint flourished about the 11th or 12th century of our era. In proof of the drying up of the Runn, some towns far inland are still pointed out as having once been ancient ports. It has, moreover, been always said that ships were wrecked and engulphed by the great catastrophe; and in the jets of black muddy water thrown out of fissures in that region, in 1819, there were cast up numerous pieces of wrought iron and ship nails.* Cones of sand 6 or 8 feet in height were at the same time formed on these lands.†

We must not conclude without alluding to a *moral* phenomenon connected with this tremendous catastrophe, which highly deserves the attention of geologists. It is stated by Sir A. Burnes, that 'these wonderful events passed *unheeded* by the inhabitants of Cutch;' for the region convulsed, though once fertile, had for a long period been reduced to sterility by want of irrigation, so that the natives were indifferent as to

* Capt. Burnes' Account.

† Capt. Macmurdo's Memoir, Ed. Phil. Journ. vol. iv. p. 106.

its fate. Now it is to this profound apathy which all but highly civilised nations feel, in regard to physical events not having an immediate influence on their worldly fortunes, that we must ascribe the extraordinary dearth of historical information concerning changes of the earth's surface, which modern observations show to be by no means of rare occurrence in the ordinary course of nature.

Since the above account was written, a description has been published of more recent geographical changes in the district of Cutch, near the mouth of the Koree, or eastern branch of the Indus, which happened in June 1845. A large area seems to have subsided, and the Sindree lake had become a salt marsh.*

Island of Sumbawa, 1815.—In April 1815, one of the most frightful eruptions recorded in history occurred in the province of Tomboro, in the island of Sumbawa (see Map, fig. 65, Vol. I. p. 587), about 200 miles from the eastern extremity of Java. In April of the preceding year the volcano had been observed in a state of considerable activity, ashes having fallen upon the decks of vessels which sailed past the coast.† The eruption of 1815 began on April 5th, but was most violent on the 11th and 12th, and did not entirely cease till July. The sound of the explosions was heard in Sumatra, at the distance of 970 geographical miles in a direct line; and at Ternate, in an opposite direction, at the distance of 720 miles. Out of a population of 12,000, in the province of Tomboro, only 26 individuals survived. Violent whirlwinds carried up men, horses, cattle, and whatever else came within their influence, into the air; tore up the largest trees by the roots, and covered the whole sea with floating timber.‡ Great tracts of land were covered by lava, several streams of which, issuing from the crater of the Tomboro Mountain, reached the sea. So heavy was the fall of ashes, that they broke into the Resident's house at Bima, 40 miles east of the volcano, and rendered it as well as many other dwellings in the town uninhabitable. On the side of Java the ashes were carried to the distance of 300 miles, and 217 towards

* Quart. Geol. Journ. vol. ii. p. 103.

† MS. of J. Crawfurd, Esq.

‡ Raffles's Java, vol. i. p. 28.

Celebes, in sufficient quantity to darken the air. The floating cinders to the westward of Sumbawa formed, on April 12th, a mass 2 feet thick, and several miles in extent, through which ships with difficulty forced their way.

The darkness occasioned in the daytime by the ashes in Java was so profound, that nothing equal to it was ever witnessed in the darkest night. Although this volcanic dust when it fell was an impalpable powder, it was of considerable weight when compressed, a pint of it weighing twelve ounces and three-quarters. 'Some of the finest particles,' says Mr. Crawfurd, 'were transported to the islands of Amboyna and Banda, which last is about 800 miles east from the site of the volcano, although the south-east monsoon was then at its height.' They must have been projected, therefore, into the upper regions of the atmosphere, where a counter-current prevailed.

Along the sea-coast of Sumbawa and the adjacent isles, the sea rose suddenly to the height of from 2 to 12 feet, a great wave rushing up the estuaries, and then suddenly subsiding. Although the wind at Bima was still during the whole time, the sea rolled in upon the shore, and filled the lower parts of the houses with water a foot deep. Every prow and boat was forced from the anchorage, and driven on shore.

The town called Tomboro, on the west side of Sumbawa, was overflowed by the sea, which encroached upon the shore so that the water remained permanently 18 feet deep in places where there was land before. Here we may observe, that the amount of subsidence of land was apparent, in spite of the ashes, which would naturally have caused the limits of the coast to be extended.

The tremulous noises and other volcanic effects of this eruption extended over an area 1,000 statute miles in diameter, having Sumbawa as its centre. It included the whole of the Molucca Islands, Java, a considerable portion of Celebes, Sumatra, and Borneo. In the Island of Amboyna, in the same month and year, the ground opened, threw out water, and then closed again.*

* Raffles's Hist. of Java, vol. i. p. 25. Ed. Phil. Journ. vol. iii. p. 389.

In conclusion, I may remind the reader, that but for the accidental presence of Sir Stamford Raffles, then governor of Java, we should scarcely have heard in Europe of this tremendous catastrophe. He required all the residents in the various districts under his authority to send in a statement of the circumstances which occurred within their own knowledge; but, valuable as were their communications, they are often calculated to excite rather than to satisfy the curiosity of geologists. They mention that similar effects, though in a less degree, had, about seven years before, accompanied an eruption of Carang Assam, a volcano in the island of Bali, west of Sumbawa; but no particulars of that great catastrophe are recorded.*

Caraccas, 1812.—On March 26, 1812, several violent shocks of an earthquake were felt in Caraccas. The surface undulated like a boiling liquid, and terrific sounds were heard underground. The whole city with its splendid churches was in an instant a heap of ruins, under which 10,000 of the inhabitants were buried. On April 5, enormous rocks were detached from the mountains. It was believed that the mountain Silla lost from 300 to 360 feet of its height by subsidence; but this was an opinion not founded on any measurement. On April 27, a volcano in St. Vincent's threw out ashes; and, on the 30th, lava flowed from its crater into the sea, while its explosions were heard at a distance equal to that between Vesuvius and Switzerland, the sound being transmitted, as Humboldt supposes, through the ground. During the earthquake which destroyed Caraccas, an immense quantity of water was thrown out at Valecillo, near Valencia, as also at Porto Caballo, through openings in the earth; and in the Lake Maracaybo the water sank. Humboldt observed that the Cordilleras, composed of gneiss and mica slate, and the country immediately at their foot, were more violently shaken than the plains.†

South Carolina and New Madrid, Missouri, 1811–12.—Previous to the destruction of La Guayra and Caraccas, in 1812, earthquakes were felt in South Carolina; and the

* Life and Services of Sir Stamford Raffles, p. 241. London, 1830.

† Humboldt's Pers. Nar. vol. iv. p. 12; and Ed. Phil. Journ. vol. i. p. 272, 1819.

shocks continued till those cities were destroyed. The valley also of the Mississippi, from the village of New Madrid to the mouth of the Ohio in one direction, and to the St. Francis in another, was convulsed in such a degree as to create new lakes and islands. It has been remarked by Humboldt in his 'Cosmos,' that the earthquake of New Madrid presents one of the few examples on record of the incessant quaking of the ground for several successive months *far from any volcano.* Flint, the geographer, who visited the country seven years after the event, informs us, that a tract of many miles in extent, near the Little Prairie, became covered with water 3 or 4 feet deep; and when the water disappeared a stratum of sand was left in its place. Large lakes of 20 miles in extent were formed in the course of an hour, and others were drained. The graveyard at New Madrid was precipitated into the bed of the Mississippi; and it is stated that the ground whereon the town is built, and the river bank for 15 miles above, sank 8 feet below their former level.* The neighbouring forest presented for some years afterwards 'a singular scene of confusion; the trees standing inclined in every direction, and many having their trunks and branches broken.'†

The inhabitants relate that the earth rose in great undulations; and when these reached a certain fearful height, the soil burst, and vast volumes of water, sand, and pit-coal were discharged as high as the tops of the trees. Flint saw hundreds of these deep chasms remaining in an alluvial soil, seven years after. As the shocks lasted throughout a period of three months the country people had time to remark that there were certain prevailing directions in which the fissures opened in their district. Being all of them familiar with the use of the axe, they felled the tallest trees and made them fall at right angles to the direction of the chasms, which usually ran from S.W. to N.E., and by stationing themselves on the trees they often escaped being swallowed up when the earth opened beneath them. At one period during this earthquake,

* Cramer's Navigator, p. 243. Pittsburg, 1821.

† Long's Exped. to the Rocky Mountains, vol. iii. p. 184.

the ground not far below New Madrid swelled up so as to arrest the Mississippi in its course, and to cause a temporary reflux of its waters. The motion of some of the shocks is described as having been horizontal, and of others perpendicular; and the vertical movement is said to have been much less desolating than the horizontal.

The above account has been reprinted exactly as it appeared in former editions of this work, compiled from the authorities which I have cited; but having more recently (March, 1846) had an opportunity myself of visiting the disturbed region of the Mississippi, and conversing with many eye-witnesses of the catastrophe, I am able to confirm the truth of those statements, and to add some remarks on the present face and features of the country. I skirted, as was before related (Vol. I. p. 453), part of the territory immediately west of New Madrid, called 'the sunk country,' which was for the first time permanently submerged during the earthquake of 1811–12. It is said to extend along the course of the White Water and its tributaries for a distance of between 70 and 80 miles north and south, and 30 miles east and west. I saw on its border many full-grown trees still standing leafless, the bottoms of their trunks several feet under water, and a still greater number lying prostrate. An active vegetation of aquatic plants is already beginning to fill up some of the shallows, and the sediment washed in by occasional floods when the Mississippi rises to an extraordinary height contributes to convert the borders of the sunk region into marsh and forest land. Even on the dry ground along the confines of the submerged area, I observed in some places that all the trees of prior date to 1811 were dead and leafless, though standing erect and entire. They are supposed to have been killed by the loosening of their roots during the repeated undulations which passed through the ground for three months in succession.

Mr. Bringier, an experienced engineer of New Orleans, who was on horseback near New Madrid when some of the severest shocks were experienced, related to me (in 1846), that 'as the waves advanced the trees bent down, and the instant afterwards, while recovering their position, they often

met those of other trees similarly inclined, so that their branches becoming interlocked, they were prevented from righting themselves again. The transit of the wave through the woods was marked by the crushing noise of countless boughs, first heard on one side and then on the other. At the same time powerful jets of water, mixed with sand, mud, and fragments of coaly matter, were cast up, endangering the lives of both horse and rider.'

I was curious to ascertain whether any vestiges still remained of these fountains of mud and water, and carefully examined between New Madrid and the Little Prairie several 'sink holes,' as they are termed. They consist of cavities from 10 to 30 yards in width, and 20 feet or more in depth, and are very conspicuous, as they interrupt the level surface of a flat alluvial plain. Round their edges I saw abundance of sand, which some of the inhabitants with whom I conversed had seen spouting from these deep holes, also fragments of decayed wood and black bituminous shale, probably drifted down at some former period in the main channel of the Mississippi, from the coal-fields farther north. I also found numerous rents in the soil left by the earthquake, some of them still several feet wide, and a yard or two in depth, although the action of rains, frosts, and occasional inundations, and especially the leaves of trees blown into them in countless numbers every autumn, have done much to fill them up. I measured the direction of some of the fissures, which usually varied from 10° to 45° W. of N., and were often parallel to each other; I found, however, a considerable diversity in their direction. Many of them are traceable for half a mile and upwards, but they might easily be mistaken for artificial trenches if resident settlers were not there to assure us that within their recollection they were 'as deep as wells.' Fragments of coaly shale were strewed along the edges of some of these open fissures, together with white sand, in the same manner as round the 'sink holes.' *

Among other monuments of the changes wrought in 1811–12, I explored the bed of a lake called Eulalie, near

* See Lyell's Second Visit to the United States, vol. ii. ch. xxxiii.

New Madrid, 300 yards long by 100 yards in width, which was suddenly drained during the earthquake. The parallel fissures by which the water escaped were not yet entirely closed, and all the trees growing on its bottom were at the time of my visit less than 34 years old. They consisted of cotton-wood, the willow, the honey-locust, and other species, differing from those clothing the surrounding higher grounds, which are more elevated by 12 or 15 feet. On them the hickory, the black and white oak, the gum and other trees, many of them of ancient date, were flourishing.

Reflections on the earthquakes of the nineteenth century.—We are now about to pass on to the events of the eighteenth century: but before we leave the consideration of those already enumerated, let us pause for a moment, and reflect how many remarkable facts of geological interest are afforded by the earthquakes above described, though they constitute but a small part of the convulsions even of half a century. New rocks have risen from the waters; new hot springs have burst out, and the temperature of others has been altered. A large tract in New Zealand has been upraised from 1 to 9 feet above its former level, and another contiguous region depressed several feet, and in the same archipelago a fault or displacement of the rocks nearly 100 miles long and about 9 feet in vertical height has been produced. The coast of Chili has been thrice permanently elevated; a considerable tract in the delta of the Indus has sunk down, and some of its shallow channels have become navigable; an adjoining part of the same district, upwards of 50 miles in length and 16 in breadth, has been raised about 10 feet above its former level; part of the great plain of the Mississippi, for a distance of 80 miles in length by 30 in breadth, has sunk down several feet; the town of Tomboro has been submerged, and 12,000 of the inhabitants of Sumbawa have been destroyed. Yet, with a knowledge of these and other terrific catastrophes, witnessed during so brief a period by the present generation, will the geologist declare with perfect composure that the earth has at length settled into a state of repose? Will he continue to assert that the changes of relative level of land and sea, so common in former ages of the world,

have now ceased? If, in the face of so many striking facts, he persists in maintaining this favourite dogma, it is in vain to hope that, by accumulating the proofs of similar convulsions during a series of antecedent ages, we shall shake his tenacity of purpose :—

> Si fractus illabatur orbis,
> Impavidum ferient ruinæ.

CHAPTER XXIX.

EARTHQUAKES OF THE EIGHTEENTH CENTURY—QUITO, 1797—SICILY, 1790—CALABRIA, FEBRUARY 5, 1783—SHOCKS CONTINUED TO THE END OF THE YEAR 1786—AUTHORITIES—AREA CONVULSED—GEOLOGICAL STRUCTURE OF THE DISTRICT—MOVEMENT IN THE STONES OF TWO OBELISKS—BOUNDING OF DETACHED MASSES INTO THE AIR—DIFFICULTY OF ASCERTAINING CHANGES OF LEVEL—SUBSIDENCE OF THE QUAY AT MESSINA—SHIFT OR FAULT IN THE ROUND TOWER OF TERRANUOVA—OPENING AND CLOSING OF FISSURES—LARGE EDIFICES ENGULPHED—DIMENSIONS OF NEW CAVERNS AND FISSURES—GRADUAL CLOSING IN OF RENTS—DERANGEMENT OF RIVER COURSES—LANDSLIPS—BUILDINGS TRANSPORTED ENTIRE TO GREAT DISTANCES—NEW LAKES—FUNNEL-SHAPED HOLLOWS IN ALLUVIAL PLAINS—CURRENTS OF MUD—FALL OF CLIFFS, AND SHORE NEAR SCILLA INUNDATED—STATE OF STROMBOLI AND ETNA DURING THE SHOCKS—ORIGIN AND MODE OF PROPAGATION OF EARTHQUAKE WAVES—DEPTH OF THE SUBTERRANEAN SOURCE OF THE MOVEMENT—NUMBER OF PERSONS WHO PERISHED DURING THE EARTHQUAKE OF 1783—CONCLUDING REMARKS.

The earthquakes of the 18th century, which we have next to consider, are so numerous that a few of them only can be mentioned. I shall select therefore such as are peculiarly illustrative of geological changes, treating of the more modern events first, and then of the others in retrospective order, according to the plan observed in the last chapter for reasons there explained.

Quito, 1797.—The convulsion of this year in Quito was remarkable for the extent of country shaken, and for the alterations caused in river courses, and still more for the floods of 'moya' or fetid mud which issued from the crater of the volcano of Tunguragua.*

Caraccas, 1790.—During an earthquake in Caraccas in 1790 the granitic soil on which the forest of Aripao grew, is said to have sunk, giving rise to a lake 800 yards in diameter, and from 80 to 100 feet in depth. The trees remained green for several months under water.

* Cavanilles, Journ. de Phys., tome xlix. p. 230. Gilbert's Annalen, bd. vi. Humboldt's Voy. p. 317.

Sicily, 1790.—Ferrara informs us that in Sicily in the same year (1790), at Santa Maria di Niscemi, some miles from Terranuova, near the south coast, the ground sank down during 7 shocks for a circumference of about 3 miles, and to the depth in one place of 30 feet. The subsidence continued for a month, and several fissures sent forth sulphur, petroleum, steam and hot water, and a stream of mud flowed out of one of them. The strata where this happened consisted of blue clay, and the site is far distant from the region both of ancient and modern volcanos in Sicily.*

Java, 1786.—During an earthquake in 1786 at Batur in Java which was followed by a volcanic eruption, the river Dotog entered one of several newly-formed rents, and continued after the shocks to pursue a subterranean course. This fact, noticed by contemporary writers, was afterwards verified by Dr. Horsfield.

EARTHQUAKE OF CALABRIA, 1783.

Of all the subterranean convulsions of the last century, that of Calabria in 1783 is almost the only one which has been so circumstantially described as materially to aid the geologist in appreciating the changes in the earth's crust which a repetition of similar events must produce in the lapse of ages. The shocks began in February of that year, and lasted for nearly 4 years, to the end of 1786. Neither in duration, nor in violence, nor in the extent of territory moved, was this convulsion remarkable, when contrasted with many experienced in other countries, both during the last and present century; nor were the alterations which it occasioned in the relative level of hill and valley, land and sea, so great as those effected by some subterranean movements in South America, in later times. The importance of the earthquake in question arises from the circumstance, that Calabria affords the first example of a region visited, both during and after the convulsions, by men possessing sufficient leisure, zeal, and scientific information to enable them to collect and describe with accuracy such physical facts as throw light on geological questions.

* Ferrara, Campi Fleg. p. 51.

Authorities.—Among the numerous authorities, Vivenzio, physician to the King of Naples, transmitted to the court a regular statement of his observations during the continuance of the shocks; and his narrative is drawn up with care and clearness.* Francesco Antonio Grimaldi, then secretary of war, visited the different provinces at the King's command, and published a most detailed description of the permanent changes in the surface.† He measured the length, breadth, and depth of the different fissures and gulphs which opened,

Fig. 114.

Map of part of Calabria shaken by the earthquake of 1783.

and ascertained their number in many provinces. His comments, moreover, on the reports of the inhabitants, and his explanations of their relations, are judicious and instructive. Pignataro, a physician residing at Monteleone, a town placed in the very centre of the convulsions, kept a register of the

* Istoria de' Tremuoti della Calabria del 1783.

† Descriz. de' Tremuoti Accad. nelle Calabria nel 1783. Napoli, 1784.

shocks, distinguishing them into four classes, according to their degree of violence. From his work, it appears that, in the year 1783, the number was 949, of which 501 were shocks of the first degree of force; and in the following year there were 151, of which 98 were of the first magnitude.

Count Ippolito, also, and many others, wrote descriptions of the earthquake; and the Royal Academy of Naples, not satisfied with these and other observations, sent a deputation from their own body into Calabria, before the shocks had ceased, who were accompanied by artists instructed to illustrate by drawings the physical changes of the district, and the state of ruined towns and edifices. Unfortunately these artists were not very successful in their representations of the condition of the country, particularly when they attempted to express, on a large scale, the extraordinary revolutions which many of the great and minor river-courses underwent But some of the plates published by the Academy are valuable; and as they are little known, I shall frequently avail myself of them to illustrate the facts about to be described.*

In addition to these Neapolitan sources of information, our countryman, Sir William Hamilton, surveyed the district, not without some personal risk, before the shocks had ceased; and his sketch, published in the Philosophical Transactions, supplies many facts that would otherwise have been lost. He has explained, in a rational manner, many events which, as related in the language of some eye-witnesses, appeared marvellous and incredible. Dolomieu also examined Calabria during the catastrophe, and wrote an account of the earthquake, correcting a mistake into which Hamilton had fallen, who supposed that a part of the tract shaken had consisted of volcanic tuff. It is, indeed, a circumstance which enhances the geological interest of the commotions which so often modify the surface of Calabria, that they are confined to a country where there are neither ancient nor modern rocks of volcanic or trappean origin; so that at some future time, when the era of disturbance shall have passed by, the cause of former revolutions will be as

* Istoria de' Fenomeni del Tremoto, &c. nell' An. 1783, posta in luce dalla Real. Accad. &c. di Nap. Napoli, 1783, fol.

latent as in parts of Great Britain now occupied exclusively by ancient marine formations.

Extent of the area convulsed.—The convulsion of the earth, sea, and air extended over the whole of Calabria Ultra, the south-east part of Calabria Citra, and across the sea to Messina and its environs; a district lying between the 38th and 39th degrees of latitude. The concussion was perceptible over a great part of Sicily, and as far north as Naples; but the surface over which the shocks acted so forcibly as to excite intense alarm did not generally exceed 500 square miles in area. That part of Calabria is composed chiefly, like the southern part of Sicily, of argillaceous strata of great thickness, containing marine shells, sometimes associated with beds of sand and limestone. For the most part these formations resemble in appearance and consistency the sub-Apennine marls, with their accompanying sands and sandstones; and the whole group bears considerable resemblance, in the yielding nature of its materials, to most of our tertiary deposits in France and England. Chronologically considered, however, the Calabrian formations are comparatively of modern date, often abounding in fossil shells referable to species now living in the Mediterranean.

We learn from Vivenzio that on the 20th and 26th of March, 1783, earthquakes occurred in the Ionian Islands, Zante, Cephalonia, and St. Maura; and in the last-mentioned island several public edifices and private houses were overthrown, and many people destroyed.

If the city of Oppido, in Calabria Ultra, be taken as a centre, and round that centre a circle be described, with a radius of 22 miles, this space will comprehend the surface of the country which suffered the greatest alteration, and where all the towns and villages were destroyed. The first shock, of February 5, 1783, threw down, in two minutes, the greater part of the houses in all the cities, towns, and villages, from the western flanks of the Apennines in Calabria Ultra to Messina in Sicily, and convulsed the whole surface of the country. Another occurred on March 28, with almost equal violence. The granitic chain which passes through Calabria from north to south, and attains the height of many thousand

feet, was shaken but slightly by the first shock, but more rudely by some which followed.

Some writers have asserted that the wave-like movements which were propagated through the recent strata, from west to east, became very violent when they reached the point of junction with the granite, as if a reaction was produced where the undulatory movement of the soft strata was suddenly arrested by the more solid rocks. But the statement of Dolomieu on this subject is the most interesting, and perhaps, in a geological point of view, the most important of all the observations which are recorded.* The Apennines, he says, which consist in great part of hard and solid granite, with some micaceous and argillaceous schists, form bare mountains with steep sides, and exhibit marks of great degradation. At their base newer strata are seen of sand and clay, mingled with shells; a marine deposit containing such ingredients as would result from the decomposition of granite. The surface of this newer (*tertiary*) formation constitutes what is called the plain of Calabria—a platform which is flat and level, except where intersected by narrow valleys or ravines, which rivers and torrents have excavated sometimes to the depth of 600 feet. The sides of these ravines are almost perpendicular; for the superior stratum, being bound together by the roots of trees, prevents the formation of a sloping bank. The usual effect of the earthquake, he continues, was to disconnect all those masses which either had not sufficient bases for their bulk, or which were supported only by lateral adherence. Hence it follows that throughout the whole length of the chain, the soil which adhered to the granite at the base of the mountains Caulone, Esope, Sagra, and Aspromonte, slid over the solid and steeply inclined nucleus, and descended somewhat lower, leaving almost uninterruptedly from St. George to beyond St. Christina, a distance of from 9 to 10 miles, a chasm between the solid granitic nucleus and the sandy soil. Many lands slipping thus were carried to a considerable distance from their former position, so as entirely to cover

* Dissertation on the Calabrian Earthquake, &c., translated in Pinkerton's Voyages and Travels, vol. v.

others; and disputes arose as to whom the property which had thus shifted its place should belong.

From this account of Dolomieu we might anticipate, as the result of a continuance of such earthquakes, first, a longitudinal valley following the line of junction of the older and newer rocks; secondly, greater disturbance in the newer strata near the point of contact than at a greater distance from the mountains; phenomena very common in other parts of Italy at the junction of the Apennine and sub-Apennine formations.

Mr. Mallet, in his valuable essay on the Dynamics of Earthquakes,* offers the following explanation of the fact to which Dolomieu has called attention. When a wave of elastic compression, of which he considers the earth-wave to consist, passes abruptly from a body having an extremely low elasticity, such as clay and gravel, into another like granite, whose elasticity is remarkably high, it changes not only its velocity but in part also its course, a portion being reflected and a portion refracted. The wave being thus sent back again produces a shock in the opposite direction, doing great damage to buildings on the surface by thus returning upon itself. At the same time, the shocks are at once eased when they get into the more elastic materials of the granitic mountains.

The surface of the country during the Calabrian earthquakes often heaved like the billows of a swelling sea, which produced a swimming in the head, like sea-sickness. It is particularly stated, in almost all the accounts, that just before each shock the clouds appeared motionless; and, although no explanation is offered of this phenomenon, it seems obviously the same as that observed in a ship at sea when it pitches violently. The clouds seem arrested in their career as often as the vessel rises in a direction contrary to their course; so that the Calabrians must have experienced precisely the same motion on the land.

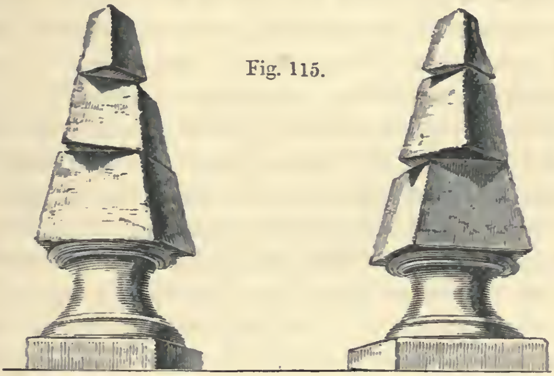
Trees, supported by their trunks, sometimes bent during the shocks to the earth, and touched it with their tops. This

* Proceed. Roy. Irish Acad. 1846, p. 26.

is mentioned as a well-known fact by Dolomieu; and he assures us that he was always on his guard against the spirit of exaggeration in which the vulgar are ever ready to indulge when relating these wonderful occurrences.

The reader must not suppose that these waves, although described as passing along the solid surface of the earth in a given direction, like a billow on the sea, have any strict analogy with the undulations of a fluid. They must be regarded as the effects of vibrations, radiating from some deep-seated point, each vibration on reaching the surface lifting up the ground, and then allowing it again to subside. The manner in which the vibratory jar reaches different points of the surface in succession according to the outline of the country, will be explained in the sequel. (See p. 136.)

Fig. 115.



Shifts in the stones of two obelisks in the Convent of S. Bruno.

The Academicians described derangements in some of the buildings of Calabria which seemed to them to indicate a whirling or vorticose movement. Thus, for example, two obelisks (fig. 115) placed at the extremities of a magnificent façade in the convent of S. Bruno, in a small town called Stefano del Bosco, were observed to have undergone a movement of a singular kind. The shock which agitated the building is described as having been horizontal and vorticose. The pedestal of each obelisk remained in its original place; but the separate stones above were turned partially round, and removed sometimes nine inches from their position without falling.

It has been suggested by Mr. Darwin, that this kind of displacement may be due to a vibratory rather than a whirling motion;* and more lately Mr. Mallet, in the paper already cited, has offered a satisfactory solution of the problem. He refers the twisting simply to an elastic wave, which has moved the pedestal forwards and back again, by an alternate horizontal motion within narrow limits; and he has succeeded in showing that a rectilinear movement in the ground may have sufficed to cause an incumbent body to turn partially round upon its bed, provided a certain relation exist between the position of the centre of gravity of the body and its centre of adherence.†

The violence of the movement of the ground upwards was singularly illustrated by what the Academicians call the 'sbalzo,' or bounding into the air, to the height of several yards, of masses slightly adhering to the surface. In some towns a great part of the pavement stones were thrown up, and found lying with their lower sides uppermost. In these cases, we must suppose that they were propelled upwards by the momentum which they had acquired; and that the adhesion of one end of the mass being greater than that of the other, a rotatory motion had been communicated to them. When the stone was projected to a sufficient height to perform somewhat more than a quarter of a revolution in the air, it pitched down on its edge, and fell with its lower side uppermost.

New fissures and changes of level.—I shall now consider, in the first place, those changes which are connected with the rending and fissuring of rocks or with alterations in the relative level of the different parts of the land; and afterwards describe those which are more immediately connected with the derangement of the regular drainage of the country, and where the force of running water co-operated with that of the earthquake.

In regard to alterations of relative level, none of the accounts establish that they were on a considerable scale; but it must always be remembered that, in proportion to the area moved is the difficulty of proving that the general level

* Journal of a Naturalist, p. 376, and ii. ib. 308.

† Proceedings Roy. Irish Acad. 1846, pp. 14–16.

has undergone any change, unless the sea-coast happens to have participated in the principal movement. Even then it is often impossible to determine whether an elevation or depression even of several feet has occurred, because there is nothing to attract notice in a band of shingle and sand of unequal breadth above the level of the sea running parallel to a coast; such bands generally marking the point reached by the waves during spring tides, or the most violent tempests. The scientific investigator has not sufficient topographical knowledge to discover whether the extent of beach has diminished or increased; and he who has the necessary local information scarcely ever feels any interest in ascertaining the amount of the rise or fall of the ground. Add to this the great difficulty of making correct observations, in consequence of the enormous waves which roll in upon a coast during an earthquake, and efface every landmark near the shore.

It is evidently in seaports alone that we can look for very accurate indications of slight changes of level; and when we find them, we may presume that they would not be rare at other points, if equal facilities of comparing relative altitudes were afforded. Grimaldi states (and his account is confirmed by Hamilton and others), that at Messina, in Sicily, the shore was rent; and the soil along the port, which before the shock was perfectly level, was found afterwards to be inclined towards the sea,—the sea itself near the 'Branchia' becoming deeper, and its bottom in several places disordered. The quay also sunk down about 14 inches below the level of the sea, and the houses in its vicinity were much fissured.*

Unfortunately we are without data for determining whether these changes were superficial only, and due to the sliding down or settling of the soil, or whether they were connected with deep-seated movements altering the relative level of sea and land.

Among various proofs of partial elevation and depression in the interior, the Academicians mention, in their Survey, that the ground was sometimes on the same level on both sides of new ravines and fissures, but sometimes there had

* Phil. Trans. 1783.

been a considerable upheaving of one side, or subsidence of the other. Thus, on the sides of long rents in the territory of Soriano, the stratified masses had altered their relative position to the extent of from 8 to 14 palms (6 to $10\frac{1}{2}$ feet).

Similar shifts in the strata are alluded to in the territory of Polistena, where there appeared innumerable fissures in the earth. One of these was of great length and depth; and in parts the level of the corresponding sides was greatly changed. (See fig. 116.)

In the town of Terranuova some houses were seen uplifted above the common level, and others adjoining sunk down into the earth. In several streets the soil appeared thrust

Fig. 116.

Deep fissure, near Polistena, caused by the earthquake of 1783.

up, and abutted against the walls of houses: a large circular tower of solid masonry, part of which had withstood the general destruction, was divided by a vertical rent, and one side was upraised, and the foundations heaved out of the ground. It was compared by the Academicians to a great tooth half extracted from the alveolus, with the upper part of the fangs exposed. (See fig. 117.)

Along the line of this shift, or 'fault,' the walls were found to adhere firmly to each other, and to fit so well, that the only sign of their having been disunited was the want of correspondence in the courses of stone on either side of the rent.

Dolomieu saw a stone well in a convent of the Augustins at Terranuova, which had the appearance of having been driven out of the earth. It resembled a small tower 8 or 9 feet in height, and a little inclined. This effect, he says, was produced by the consolidation and consequent sinking of the sandy soil in which the well was dug.

In some walls which had been thrown down, or violently shaken, in Monteleone, the separate stones were parted from the mortar, so as to leave an exact mould where they had rested; whereas in other cases the mortar was ground to dust between the stones.

Fig. 117.

Shift or 'fault' in the Round Tower of Terranuova in Calabria, occasioned by the earthquake of 1783.

It appears that the wave-like motions often produced effects of the most capricious kind. Thus, in some streets of Monteleone, every house was thrown down but one; in others, all but two; and the buildings which were spared were often scarcely in the least degree injured. In many cities of Calabria, all the most solid buildings were thrown down, while those which were slightly built escaped; but at Rosarno, as also at Messina in Sicily, it was precisely the reverse, the massive edifices being the only ones that stood.

As the earthquake-wave passed along the surface of the ground, rents and chasms opened and closed alternately, so

that houses, trees, cattle and men were first engulphed in an instant, and then the sides of the fissures coming together again no vestige of them was to be seen on the surface. We may conceive the same effect to be produced on a small scale, if, by some mechanical force, a pavement composed of large flags of stone should be raised up, and then allowed to fall suddenly, so as to resume its original position. If any small pebbles happened to be lying on the line of contact of two flags, they would fall into the opening when the pavement rose, and be swallowed up, so that no trace of them would appear after the subsidence of the stones. In many instances, individuals are said to have been swallowed up by one shock,

Fig. 118.

Fissures near Jerocarne, in Calabria, caused by the earthquake of 1783.

and then thrown out again alive, together with large jets of water, by the shock which immediately succeeded.

At Jerocarne, a country which, according to the Academicians, was *lacerated* in a most extraordinary manner, the fissures ran in every direction 'like cracks on a broken pane of glass.' (See fig. 118.)

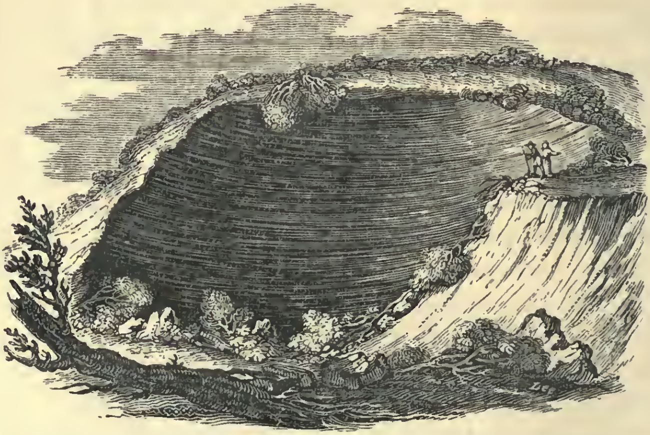
As we learn from Dolomieu that the direction of the new chasms and fissures throughout Calabria was usually parallel to the course of ravines and gorges pre-existing in their neighbourhood, we may conclude that not a few of them were due to a comparatively superficial movement of the ground in a sideway direction.

In the vicinity of Oppido, the central point where the shocks of the earthquake were most violent, many houses were swallowed up by the yawning earth, which closed immediately over them. In the adjacent district, also, of Cannamaria four farm-houses, several oil-stores, and some spacious dwelling-houses were so completely engulphed in one chasm, that not a vestige of them was afterwards discernible. The same phenomenon occurred at Terranuova, S. Christina, and Sinopoli. The Academicians state particularly, that when deep abysses had opened in the argillaceous strata of Terranuova, and houses had sunk into them, the sides of the chasms closed with such violence, that, on excavating afterwards to recover articles of value, the workmen found the contents and detached parts of the buildings jammed together so as to become one compact mass.

Sir W. Hamilton was shown several deep fissures in the vicinity of Mileto, which, although not one of them was above a foot in breadth, had opened so wide during the earthquake as to swallow an ox and nearly one hundred goats. The Academicians also found, on their return through districts which they had passed at the commencement of their tour, that many rents had, in that short interval, gradually closed in, so that their width had diminished several feet, and the opposite walls had sometimes nearly met. It is natural that this should happen in argillaceous strata, while, in more solid rocks, we may expect that fissures will remain open for ages. Should this be ascertained to be a general fact in countries convulsed by earthquakes, it may afford a satisfactory explanation of a common phenomenon in mineral veins. Such veins often retain their full size so long as the rocks consist of limestone, granite, or other indurated materials; but they contract their dimensions, become mere threads, or are even entirely cut off, where masses of an argillaceous nature are interposed. If we suppose the filling up of fissures with metallic and other ingredients to be a process requiring ages for its completion, it is obvious that the opposite walls of rents, where strata consist of yielding materials, must collapse or approach very near to each other before sufficient time is allowed for the accretion of a large quantity of veinstone.

Some of the chasms which opened seem to imply the sinking down of the earth into subterranean cavities. One of these was observed by the Academicians on the sloping

Fig. 119.



Chasm formed by the earthquake of 1783 near Oppido, in Calabria.

side of a hill near Oppido, into which part of a vineyard and a considerable number of olive trees with a large quantity of soil were precipitated. Yet a great gulf remained after the

Fig. 120.

Chasm in the hill of St. Angelo, near Soriano, in Calabria, caused by the earthquake of 1783.

shock, in the form of an amphitheatre, 500 feet long and 200 feet deep. (See fig. 119.)

According to Grimaldi, many fissures and chasms, formed by the first shock of February 5th, were greatly widened, lengthened, and deepened by the violent convulsions of March 28th. Some of these were nearly a mile in length, and from 150 to more than 200 feet in depth, usually straight, but some of them in the form of a crescent. The annexed cut (fig. 120) represents one by no means remarkable for its dimensions, which remained open by the side of a small pass over the hill of St. Angelo, near Soriano. The small river Mesima is seen in the foreground.

Formation of circular hollows and new lakes.—In the report of the Academy, we find that some plains were covered with

Fig. 121.

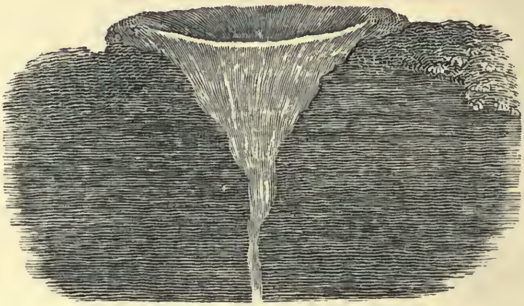
Circular hollows in the plain of Rosarno, formed by the earthquake of 1783.

circular hollows, for the most part about the size of carriage-wheels, but often somewhat larger or smaller. When filled with water to within a foot or two of the surface, they appeared like wells; but, in general, they were filled with dry sand, sometimes with a concave surface, and at other times convex. (See fig. 121.) On digging down, they found them to be funnel-shaped, and the moist loose sand in the centre marked the tube up which the water spouted. The annexed cut (fig. 122) represents a section of one of these

inverted cones when the water had disappeared, and nothing but dry micaceous sand remained.

A small circular pond of similar character was formed not far from Polistena (see fig. 123); and in the vicinity of Seminara, a lake was suddenly caused by the opening of a great chasm, from the bottom of which water issued. This

Fig. 122.



Section of one of the circular hollows formed in the plain of Rosarno.

lake was called Lago del Tolfilo. It extended 1,785 feet in length, by 937 in breadth, and 52 in depth. The inhabitants, dreading the miasma of this stagnant pool, endeavoured, at

Fig. 123.

Circular pond near Polistena in Calabria, caused by the earthquake in 1783.

great cost, to drain it by canals, but without success, as it was fed by springs issuing from the bottom of the deep chasm.

Cones of sand thrown up.—Many of the appearances ex-

hibited in the alluvial plains, such as springs spouting up their water like fountains at the moment of the shock, have been supposed to indicate the alternate rising and sinking of the ground. The first effect of the more violent shocks was usually to dry up the rivers, but they immediately afterwards overflowed their banks. In marshy places, an immense number of cones of sand were thrown up. These appearances Hamilton explains, by supposing that the first movement raised the fissured plain from below upwards, so that the rivers and stagnant waters in bogs sank down, or at least were not upraised with the soil. But when the ground returned with violence to its former position, the water was thrown up in jets through fissures.

The phenomenon, according to Mr. Mallet, may be simply an accident contingent on the principal cause of disturbance, the rapid transit of the earth-wave. 'The sources,' he says, 'of copious springs usually lie in flat plates or fissures filled with water, whether issuing from solid rock, or from loose materials; now, if a vein, or thin flat cavity filled with water, be in such a position that the plane of the plate of water or fissure be transverse to the line of transit of the earth-wave, the effect of the arrival of the earth-wave at the watery fissure will be, at the instant, to compress its walls more or less together, and so squeeze out the water, which will, for a moment, gush up at the springhead like a fountain, and again remain in repose after the transit of the wave.'

Derangement of river-courses.—Vivenzio states, that near Sitizzano a valley was nearly filled up to a level with the high grounds on each side, by the enormous masses detached from the boundary hills, and cast down into the course of two streams. By this barrier a lake was formed of great depth, about 2 miles long and 1 mile broad. The same author mentions that, upon the whole, there were 50 lakes occasioned during the convulsions: and he assigns localities to all of these. The government surveyors enumerated 215 lakes; but they included in this number many small ponds.

Such lakes and ponds could only be permanent where rivers and brooks were diverted into an entirely new course, whether into some adjoining ravine or into a different part of the

same alluvial plain. In cases where the new barrier obstructs the whole of the drainage, the water flowing over the dam will gradually deepen a new channel in it, and drain the lake.*

From each side of the deep valley or ravine of Terranuova, enormous masses of the adjoining flat country were detached, and cast down into the course of the river, so as to give rise to lakes. Oaks, olive-trees, vineyards, and corn, were often seen growing at the bottom of the ravine, as little injured as their former companions, which still continued to flourish in the plain above, at least 500 feet higher, and at the distance of about $\frac{3}{4}$ of a mile. In one part of this ravine was a mass, 200 feet high and about 400 feet circumference at its base, which had been detached by some former earthquake. It is well attested, that this mass travelled down the ravine nearly 4 miles, having been put in motion by the earthquake of February 5. Hamilton, after examining the spot, declared that this phenomenon might be accounted for by the declivity of the valley, the great abundance of rain which fell, and the great weight of the alluvial matter which pressed behind it. Dolomieu also alludes to the fresh impulse derived from other masses falling, and pressing upon the rear of those first set in motion.

The first account sent to Naples of the two great slides or landslips above alluded to, which caused a great lake near Terranuova, was couched in these words:—'Two mountains on the opposite sides of a valley walked from their original positions until they met in the middle of the plain, and there joining together, they intercepted the course of a river,' &c. The expressions here used resemble singularly those applied to phenomena, probably very analogous, which are said to have occurred at Fez, during the great Lisbon earthquake, as also in Jamaica and Java at other periods.

Not far from Soriano, the houses of which were levelled to the ground by the great shock of February, a small valley, containing a beautiful olive-grove, called Fra Ramondo, underwent a most extraordinary revolution. Innumerable fissures first traversed the river-plain in all directions, and

* See Robert Mallet, Neapolitan Earthquake of 1857, vol. ii. p. 372.

absorbed the water until the argillaceous substratum became soaked, so that a great part of it was reduced to a state of fluid paste. Strange alterations in the outline of the ground were the consequence, as the soil to a great depth was easily moulded into any form. In addition to this change, the ruins of the neighbouring hills were precipitated into the hollow; and while many olives were uprooted, others remained growing on the fallen masses, and inclined at various angles. (See fig. 124.) The small river Caridi was entirely concealed for many days; and when at length it reappeared, it had shaped for itself a new channel.

Near Seminara an extensive olive-ground and orchard were

Fig. 124.

Changes of the surface at Fra Ramondo, near Soriano, in Calabria.

1. Portion of a hill covered with olives thrown down.
2. New bed of the river Caridi.
3. Town of Soriano.

hurled to a distance of 200 feet, into a valley 60 feet in depth. At the same time a deep chasm was riven in another part of the high platform from which the orchard had been detached, and the river immediately entered the fissure, leaving its former bed completely dry. A small inhabited house, standing on the mass of earth carried down into the valley, went along with it entire, and without injury to the inhabitants. The olive-trees, also, continued to grow on the land which

had slid into the valley, and bore the same year an abundant crop of fruit.

Two tracts of land on which a great part of the town of Polistena stood, consisting of some hundreds of houses, travelled into a contiguous ravine, and nearly across it, about half a mile from their original site; and what is most extraordinary, several of the inhabitants were dug out from the ruins alive and unhurt.

Two tenements, near Mileto, called the Macini and Vaticano, occupying an extent of ground about 1 mile long and ½ a mile broad, were carried for 1 mile down a valley. A thatched cottage, together with large olive and mulberry trees, most of which remained erect, were carried uninjured to this extraordinary distance. According to Hamilton, the surface removed had been long undermined by rivulets, which

Fig. 125.

Landslips near Cinquefrondi, caused by the earthquake of 1783.

were afterwards in full view on the bare spot deserted by the tenements. The earthquake seems to have opened a passage in the adjoining argillaceous hills, which admitted water charged with loose soil into the subterranean channels of the rivulets immediately under the tenements, so that the foundations of the ground set in motion by the earthquake were loosened. An example of subsidence, where the edifices were not destroyed, is mentioned by Grimaldi, as having

taken place in the city of Catanzaro, the capital of the province of that name. The houses in the quarter called San Giuseppe subsided with the ground to various depths from 2 to 4 feet, but the buildings remained uninjured. Among other territories, that of Cinquefrondi was greatly convulsed, various portions of soil being raised or sunk, and innumerable fissures traversing the country in all directions (see fig. 125). Along the flanks of a small valley in this district there appears to have been an almost uninterrupted line of landslips.

Near S. Lucido, among other places, the soil is described as having been 'dissolved,' so that large torrents of mud inundated all the low grounds, like lava. Just emerging from this mud, the tops only of trees and of the ruins of farm-houses were seen. Two miles from Laureana, the swampy soil in two ravines became filled with calcareous matter, which oozed out from the ground immediately before the first great shock. This mud, rapidly accumulating, began, ere long, to roll onward, like a flood of lava, into the valley, where the two streams uniting, moved forward with increased impetus from east to west. It now presented a breadth of 225 feet by 15 in depth, and, before it ceased to move, covered a surface equal in length to an Italian mile. In its progress it overwhelmed a flock of 30 goats, and tore up by the roots many olive and mulberry trees, which floated like ships upon its surface. When this calcareous lava had ceased to move, it gradually became dry and hard, during which process the mass was lowered 7½ feet. It contained fragments of earth of a ferruginous colour, and emitting a sulphureous smell.

If our space permitted, we might fill a volume with local details of landslips, which the different authors above alluded to supply, showing to how great an extent the power of rivers to widen valleys is increased where earthquakes are of periodical occurrence. A geologist can never fully understand the manner in which valleys have been formed until he duly appreciates the part which subterranean movements repeated at long intervals play in combination with rivers, during that lapse of ages which must always be required for

the elevation of a country to the height of many hundreds of feet above the level of the sea.

Time must be allowed in the intervals between distinct convulsions, for running water to clear away the ruins caused by landslips, otherwise the fallen masses will serve as buttresses, and prevent the succeeding earthquake from exerting its full power. The sides of the valley must be again cut away by the stream, and made to form precipices and overhanging cliffs, before the next shock can take effect in the same manner.

Fall of the sea-cliffs.—Along the sea-coast of the Straits of Messina, near the celebrated rock of Scilla, the fall of huge masses detached from the bold and lofty cliffs overwhelmed many villas and gardens. At Gian Greco, a continuous line of cliff, for a mile in length, was thrown down. Great agitation was frequently observed in the bed of the sea during the shocks, and, on those parts of the coast where the movement was most violent, all kinds of fish were taken in abundance, and with unusual facility. Some rare species, as that called Cicirelli, which usually lie buried in the sand, were taken on the surface of the waters in great quantity. The sea is said to have boiled up near Messina and to have been agitated as if by a copious discharge of vapours from its bottom.

Shore near Scilla inundated.—The prince of Scilla had persuaded a great part of his vassals to betake themselves to their fishing-boats for safety, and he himself had gone on board. On the night of February 5, when some of the people were sleeping in the boats, and others on a level plain slightly elevated above the sea, the earth rocked, and suddenly a great mass was torn from the contiguous Mount Jaci, and thrown down with a dreadful crash upon the plain. Immediately afterwards, the sea, rising more than 20 feet above the level of this low tract, rolled foaming over it, and swept away the multitude. It then retreated, but soon rushed back again with greater violence, bringing with it some of the people and animals it had carried away. At the same time every boat was sunk or dashed against the beach, and some of them were swept far inland. The aged prince, with 1,430 of his people, was destroyed.

State of Stromboli and Etna during the shocks.—The inhabitants of Pizzo remarked that, on February 5, 1783, when the first great shock affected Calabria, the volcano of Stromboli, which is in full view of that town, and at the distance of about 50 miles, smoked less, and threw up a less quantity of inflamed matter, than it had done for some years previously. On the other hand, the great crater of Etna is said to have given out a considerable quantity of vapour towards the beginning, and Stromboli towards the close, of the commotions. But as no eruption happened from either of these great vents during the whole earthquake, the sources of the Calabrian convulsions, and of the volcanic fires of Etna and Stromboli, appear to be very independent of each other; unless, indeed, they have the same mutual relation as Vesuvius and the volcanos of the Phlegræan Fields and Ischia, a violent disturbance in one district serving as a safety-valve to the other, and both never being in full activity at once.

Origin and mode of propagation of earthquake-waves.—We have already hinted in Chapter XXIII. that there are good reasons for suspecting that the subterranean causes of the earthquake and volcano are the same. In what manner portions of the solid crust of the earth may be melted from time to time so as to form reservoirs of fused matter at various depths, will be considered in Chapter XXXII. Assuming for the present the existence of such reservoirs of liquid lava in the interior, it is not difficult to understand how steam may be generated whenever rain-water or the waters of the sea, percolating through rocks, gain access to such lava, and how, when steam is generated, the incumbent crust of the earth may be rent and dislocated.

During such movements fissures may be formed and injected with gaseous or fluid matter, which may sometimes fail to reach the surface, while at other times it may be expelled through volcanic vents, stufas and hot springs. When the strain on the rocks has caused them to split, or the roofs of pre-existing fissures or caverns have been made to fall in, vibratory jars will be produced and propagated in all directions, like waves of sound through the crust of the earth with varying velocity, according to the violence of the

original shock, and the density or elasticity of the substances through which they pass. They will travel, for example, faster through granite than through limestone, and more rapidly through the latter than through wet clay, but the rate will be uniform through the same homogeneous medium. To the inhabitants of a shaken district the wave or vibration appears to radiate horizontally, outwards from the spot on the surface where it is first felt; but the force does not really operate in a horizontal direction like a wave caused by a pebble on the surface of a pond, for at every point except that immediately above the focus of the shock it comes up obliquely from below, causing the ground to move forwards

Fig. 126.

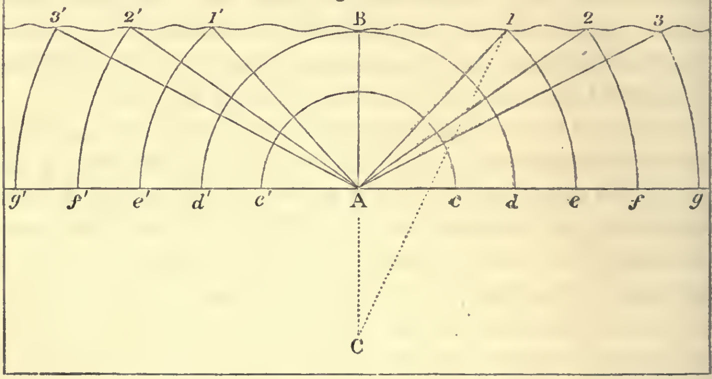


Diagram showing the mode in which an earthquake-wave is transmitted from a subterranean focus of disturbance such as A.

A. Focus of earthquake.

B. Seismic vertical, or point where the shock first reaches the surface.

C. Supposed focus of greater depth. Here the line C, 1, representing the angle of emergence, is steeper than the line A, 1. (See p. 139.)

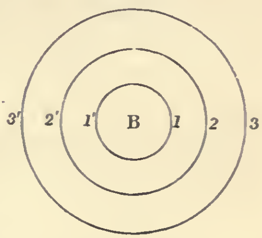
c, c′, d, d′, etc. Section of spherical shells showing the manner in which the earthquake-wave is propagated in all directions from the centre of disturbance, A.

1, 1′, Coseismic points, or points on the surface reached simultaneously by the earthquake-wave. So also 2, 2′, 3, 3′.

and then backwards in a more or less horizontal direction, so that all objects which do not participate fully in the movements, such as the walls of a building, appear to move in a direction contrary to that of the ground, and fall by their own weight or inertia. The mode in which the wave is transmitted will be best understood by the accompanying diagram, fig. 126. Suppose the subterranean centre of disturbance to be several miles below the surface or at A, the

crust of the earth being homogeneous, the shock will proceed in all directions as a wave of compression displacing the particles of the vibrating medium for a certain space, and then allowing them to recover their original position usually without fracture of the rock. The wave moves in the form of a series of spherical shells, sections of which are represented in the diagram at *c c′*, *d d′*, &c. When the movement extends to the circle *d d′* the earthquake will be first felt at the surface at a point immediately above A. This point B, where the shock will be felt most violently by the inhabitants as being nearest to the original impulse, is called the seismic vertical. The vibrations will reach the points 1 and 1′ some seconds later, according to the distance of such points from the focus A. The wave will successively reach the points 2 and 2′, and 3 and 3′, and its emergence at the surface of the country will take place in a series of concentric rings receding farther and farther from B where the shock was first felt, as in fig. 127. The wave therefore, or vibratory jar, although having the appearance of being propagated horizontally in all directions from B, is in reality transmitted direct from A. The circles 1 1′, 2 2′, and 3 3′ in figs. 126 and 127 are called coseismal circles, because all points in their circumference are simultaneously shaken. The reader will observe that all these spherical shells *c c′*, *d d′*, and the points of emergence, 1, 2, 3, &c., relate to the continuous transmission through the earth of a single shock, and not to a series of separate waves following each other. Mr. Robert Mallet and the late Mr. Hopkins have endeavoured to devise instruments and methods of observation, by which the rate of transit of the earthquake-wave, and the depth of the focus of disturbance, might be measured.

Fig. 127.



B. Seismic vertical.
1, 2, 3. Coseismic points with 1′, 2′, 3′, respectively.

Mr. Mallet* has the merit of having been the first to make a practical application of the rules deduced from mechanical

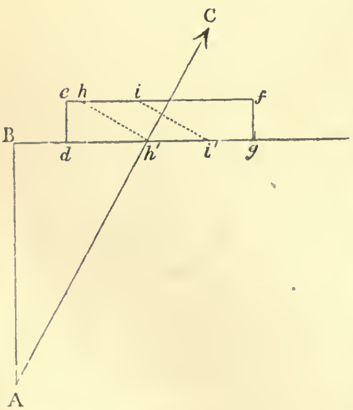
* Great Neapolitan Earthquake of 1857; in two vols. London, 1862.

principles bearing on this subject. With this object he visited part of the Neapolitan territory, shortly after the great earthquake of December, 1857. The region most violently shaken at that period was about 40 miles east of Salerno, in latitude 40° 30′ N., wholly to the north of the district convulsed in 1783. Although many towns were then laid in ruins, and there was much loss of life, the destruction was by no means so great as that of 1783, and the changes wrought in the river-courses were not on so grand a scale.

To obtain the seismic vertical Mr. Mallet observed the direction in which chimneys, urns, and statues had been thrown down from the tops of high buildings. Such bodies, in consequence of their inertia, usually fall backwards in the direction from which the shock comes, but sometimes they are thrown forwards. In either case they indicate the direction of the shocks, and two or more such lines of direction prolonged to their point of intersection give the seismic vertical. That point being found, the next step is to ascertain the angle at which the wave emerged at different points at the surface.

Suppose a rectangular building *d*, *e*, *f*, *g* (fig. 128), to stand with its principal walls in the direction of the shock, and the earthquake-wave to emerge in the direction A, C. The shock will tend to produce fissures *h h′*, *i i′*, at right angles to its own path. The inclination of A, C, to the horizon, or the angle of emergence, being thus known by reference to these fissures, we obtain the position of the focus A, by imagining the line C, *h′*, to be prolonged till it meets the vertical line B, A.

Fig. 128.



By referring to the former diagram, fig. 126, the reader will at once see that the angle of emergence of the wave at any given distance from the seismic vertical, B, will depend upon the depth of the focus;

in other words, it will be always steeper as the depth increases, as the line C, 1, for example, is more steeply inclined than A, 1.

By aid of a dynamical formula which we need not cite here, Mr. Mallet came to the conclusion that the depth of the original shock in 1857 did not exceed 7 or 8 miles, and although this can only be a rough approximation to the truth, it is of considerable interest, and the repetition of such investigations may hereafter lead to more reliable results, especially when observations in regard to the time, direction, and intensity of the shocks shall have been made with scientific care at the moment of the convulsion. Such observations require the aid of delicate instruments, and the problem is exceedingly complicated, far more so than the reader may have inferred from the simple illustration above given. For in the first place the shock which produces the vibration or earthquake-wave does not give rise to a single movement, as above supposed, but to two movements, one longitudinal and the other transverse; the second of which at the outset follows the principal one almost instantaneously, and is at right angles to it; but, as this latter vibration travels somewhat slower than the former, it reaches the surface, if the distance be considerable, after a distinct interval of time, and often does more mischief to buildings than the first. It will also be seen by the elaborate report of Mr. Hopkins* that the earthquake-wave, when it passes through rocks differing in density and elasticity, changes in some degree not only its velocity but its direction, being both refracted and reflected in a manner analogous to that of light when it passes from one medium to another of a different density. When the shock traverses the earth's crust through a thickness of several miles, it will encounter a great variety of rocks as well as rents and faults by which the course of the vibratory movements will be more or less interfered with. The fracture also of buildings is considerably modified by the nature of their component materials, and of the coherence of the mortar by which stones or bricks are cemented together.

* Geological Theories of Elevation and Earthquakes, Brit. Assoc. 1847, p. 33.

We must make due allowance therefore for the uncertainty of the data at Mr. R. Mallet's disposal when he attempted to compute the depth beneath the surface at which the shock of 1857 originated, and it is still more difficult for us to form a probable conjecture as to the distance from the surface of the point from which the subterranean movements of 1783 may have proceeded. It is a matter, however, of general interest that Mr. Mallet deduces from all the facts at present known to him respecting the movements of earthquakes, that the subterranean points where the shocks originate are never very deep, perhaps never exceeding thirty geographical miles; a very important conclusion should it hereafter be confirmed by observation and theory.

Number of persons who perished during the earthquake of 1783.—The number of persons who perished during the earthquake in the two Calabrias and Sicily, is estimated by Hamilton at about 40,000: and about 20,000 more died by epidemics, which were caused by insufficient nourishment, exposure to the atmosphere, and malaria, arising from the new stagnant lakes and pools.

By far the greater number were buried under the ruins of their houses; but many were burnt to death in the conflagrations which almost invariably followed the shocks. These fires raged the more violently in some cities, such as Oppido, from the immense magazines of oil which were consumed.

Many persons were engulphed in deep fissures, especially the peasants when flying across the open country, and their skeletons may perhaps be buried at various depths in the earth to this day.

When Dolomieu visited Messina after the shock of February 5, he describes the city as still presenting, at least at a distance, an imperfect image of its ancient splendour. Every house was injured, but the walls were standing: the whole population had taken refuge in wooden huts in the neighbourhood, and all was solitude and silence in the streets: it seemed as if the city had been desolated by the plague. 'But when I passed over to Calabria, and first beheld Polistena, the scene of horror almost deprived me of my faculties; my mind was filled with mingled compassion and terror;

nothing had escaped; all was levelled with the dust; not a single house or piece of wall remained; on all sides were heaps of stone so destitute of form that they gave no conception of there ever having been a town on the spot. The stench of the dead bodies still rose from the ruins. I conversed with many persons who had been buried for three, four, or even for five days; I questioned them respecting their sensations in so dreadful a situation, and they agreed that, of all the physical evils they endured, thirst was the most intolerable; and that their mental agony was increased by the idea that they were abandoned by their friends, who might have rendered them assistance.*

It is supposed that about a fourth part of the inhabitants of Polistena, and of some other towns, were buried alive, and might have been saved had there been no want of hands; but in so general a calamity, where each was occupied with his own misfortunes or those of his family, aid could rarely be obtained. Neither tears, nor supplications, nor promises of high rewards were listened to. Many acts of self-devotion, prompted by parental and conjugal tenderness, or by friendship, or the gratitude of faithful servants, are recorded; but individual exertions were, for the most part, ineffectual. It frequently happened, that persons in search of those most dear to them could hear their moans—could recognise their voices—were certain of the exact spot where they lay buried beneath their feet, yet could afford them no succour. The piled mass resisted all their strength, and rendered their efforts of no avail.

At Terranuova, four Augustin monks, who had taken refuge in a vaulted sacristy, the arch of which continued to support an immense pile of ruins, made their cries heard for the space of four days. One only of the brethren of the whole convent was saved, and 'of what avail was his strength to remove the enormous weight of rubbish which had overwhelmed his companions?' He heard their voices die away gradually; and when afterwards their four corpses were disinterred, they were found clasped in each other's arms. Affecting narratives

* Pinkerton's Voyages and Travels, vol. v. as cited above, p. 117, note.

are preserved of mothers saved after the fifth, sixth, and even seventh day of their interment, when their infants or children had perished with hunger.

It might have been imagined that the sight of sufferings such as these would have been sufficient to awaken sentiments of humanity and pity in the most savage breasts; but while some acts of heroism are related, nothing could exceed the general atrocity of conduct displayed by the Calabrian peasants: they abandoned the farms, and flocked in great numbers into the towns—not to rescue their countrymen from a lingering death, but to plunder. They dashed through the streets, fearless of danger, amid tottering walls and clouds of dust, trampling beneath their feet the bodies of the wounded and half-buried, and often stripping them, while yet living, of their clothes.*

But to enter more fully into these details would be foreign to the purpose of the present work, and several volumes would be required to give the reader a just idea of the sufferings which the inhabitants of many populous districts have undergone during the earthquakes of the last 150 years. A bare mention of the loss of life—as that 50,000 or 100,000 souls perished in one catastrophe—conveys to the reader no idea of the extent of misery inflicted: we must learn, from the narratives of eye-witnesses, the various forms in which death was encountered, the numbers who escaped with loss of limbs or serious bodily injuries, and the multitude who were suddenly reduced to penury and want. It has been often remarked that the dread of earthquakes is strongest in the minds of those who have experienced them most frequently; whereas, in the case of almost every other danger, familiarity with peril renders men intrepid. The reason is obvious—scarcely any part of the mischief apprehended in this instance is imaginary; the first shock is often the most destructive; and, as it may occur in the dead of the night, or if by day, without giving the least warning of its approach, no forethought can guard against it; and when the convulsion has begun, no skill, or courage, or presence of mind, can point

* Dolomieu, Pinkerton's Voyages and Travels, vol. v.

out the path of safety. During the intervals, of uncertain duration (lasting perhaps for centuries), between the more fatal shocks, slight tremors of the soil are not unfrequent; and as these sometimes precede more violent convulsions, they become a source of anxiety and alarm. The terror arising from this cause alone is of itself no inconsiderable evil.

Although sentiments of pure religion are frequently awakened by these awful visitations, yet we more commonly find that an habitual state of fear, a sense of helplessness, and a belief in the futility of all human exertions, prepare the minds of the vulgar for the influence of a demoralising superstition.

Where earthquakes are frequent, there can never be perfect security of property under the best government; industry cannot be assured of reaping the fruits of its labour; and the most daring acts of outrage may occasionally be perpetrated with impunity, when the arm of the law is paralysed by the general consternation. It is hardly necessary to add, that the progress of civilisation and national wealth must be retarded by convulsions which level cities to the ground, destroy harbours, throw down bridges, render roads impassable, and cause the most cultivated valley-plains to be covered with lakes, or the ruins of adjoining hills.

In regions exposed to the frequent recurrence of severe shocks, experience and scientific knowledge might, no doubt, alleviate the evil.

The Calabrian towns of mediæval date were most of them perched, for the purposes of defence and security, on the tops of isolated hills, where they are said to be rocked by every shock like sailors on the top of a mast.* These sites have usually precipices on several sides, over the edges of which the tottering buildings may readily be precipitated together with some of the ground on which their foundations repose. When towns are placed in the more open country, and constructed on such a plan, and of such materials as are best suited to lessen the danger, the loss of life must be sensibly

* Mallet, Neapolitan Earthquake of 1857, vol. i. p. 30.

diminished. That architects do not despair of successfully contending with the danger, is shown by their frequently advertising their houses in Sicily as earthquake-proof.

I shall endeavour to point out in the sequel, that the general tendency of subterranean movements, when their effects are considered for a sufficient lapse of ages, is eminently beneficial, and that they constitute an essential part of that mechanism by which the integrity of the habitable surface is preserved, and the very existence and perpetuation of dry land secured. Why the working of this same machinery should be attended with so much evil, is a mystery far beyond the reach of our philosophy, and must probably remain so until we are permitted to investigate, not our planet alone and its inhabitants, but other parts of the moral and material universe with which they may be connected. Could our survey embrace other worlds, and the events, not of a few centuries only, but of periods as indefinite as those with which geology renders us familiar, some apparent contradictions might be reconciled, and some difficulties would doubtless be cleared up. But even then, as our capacities are finite, while the scheme of the universe may be infinite, both in time and space, it is presumptuous to suppose that all sources of doubt and perplexity would ever be removed. On the contrary, they might, perhaps, go on augmenting in number, although our confidence in the wisdom of the plan of Nature should increase at the same time; for it has been justly said, that the greater the circle of light, the greater the boundary of darkness by which it is surrounded.*

* Sir H. Davy, Consolations in Travel, p. 246.

CHAPTER XXX.

EARTHQUAKES—*continued*.

EARTHQUAKE OF JAVA, 1772—TRUNCATION OF A LOFTY CONE—ST. DOMINGO, 1770—LISBON, 1755—GREAT AREA OVER WHICH THE SHOCKS EXTENDED—RETREAT OF THE SEA—PROPOSED EXPLANATIONS—CONCEPTION BAY, 1751—PERMANENT ELEVATION—PERU, 1746—JAVA, 1699—RIVERS OBSTRUCTED BY LANDSLIPS—SUBSIDENCE IN SICILY, 1693—MOLUCCAS, 1693—JAMAICA, 1692—LARGE TRACTS ENGULPHED—PORTION OF PORT ROYAL SUNK—AMOUNT OF CHANGE IN THE LAST 170 YEARS—ELEVATION AND SUBSIDENCE OF LAND IN BAY OF BAIÆ—EVIDENCE OF THE SAME AFFORDED BY THE TEMPLE OF SERAPIS.

IN this chapter, I shall conclude my remarks on the earthquakes of the 18th century, and then pass on to those of earlier date respecting which we have information which may be of interest to the geologist.

Java, 1772.—*Truncation of a lofty cone.*—In the year 1772, Papandayang, formerly one of the loftiest volcanos in the island of Java, was in eruption. Before all the inhabitants on the declivities of the mountain could save themselves by flight, the ground is said to have given way, and a great part of the volcano to have fallen in and disappeared. It was estimated that an extent of ground of the mountain itself and its immediate environs, 15 miles long and full 6 broad, was by this commotion swallowed up in the bowels of the earth. Forty villages were destroyed, some being engulphed and some covered by the substances thrown out on this occasion, and 2,957 of the inhabitants perished. A proportionate number of cattle were also killed, and most of the plantations of cotton, indigo, and coffee in the adjacent districts were buried under the volcanic matter. This catastrophe appears to have resembled, although on a grander scale, that of the ancient Vesuvius in the year 79. The cone was reduced in height from 9,000 to about 5,000 feet; and,

as vapours still escape from the crater on its summit, a new cone may one day rise out of the ruins of the ancient mountain, as the modern Vesuvius has risen from the remains of Somma.*

Junghuhn, who examined the mountain in 1842, was unable to obtain positive proof that there had been a sinking in of the ground, and concluded that, if any, it must have been near the summit of the cone, or where a new crater was formed. He found that the towns and villages destroyed were far distant from the summit, and buried under a mass of ejected materials; so that they seem to have suffered the fate of Herculaneum and Pompeii, and the lowering of the mountain was probably due for the most part to explosion, rather than to engulphment.

St. Domingo, 1770.—During a tremendous earthquake which destroyed a great part of St. Domingo, innumerable fissures were caused throughout the island, from which mephitic vapours emanated and produced an epidemic. *Hot springs* burst forth in many places where there had been no water before; but after a time they ceased to flow.†

In a previous earthquake, in November 1751, a violent shock destroyed the capital, Port-au-Prince, and part of the coast, twenty leagues in length, sank down, and has ever since formed a bay of the sea.‡

Hindostan, 1762.—The town of Chittagong, in Bengal, was violently shaken by an earthquake, on April 2, 1762, the earth opening in many places, and throwing up water and mud of a sulphureous smell. At a place called Bardavan, a large river was dried up; and at Bar Charra, near the sea, a tract of ground sank down, and 200 persons, with all their cattle, were lost. It is said that 60 square miles of the Chittagong coast suddenly and permanently subsided during this earthquake, and that Ces-lung-Toom, one of the Mug mountains, entirely disappeared, and another sank so low, that its summit only remained visible. Four hills are also

* Dr. Horsfield, Batav. Trans. vol. viii. p. 26. Raffles's account (History of Java, vol. i.) is derived from Horsfield.

† Essai sur l'Hist. Nat. de l'Isle de St. Domingue. Paris, 1776.

‡ Hist. de l'Acad. des Sciences. 1752. Paris.

described as having been variously rent asunder, leaving open chasms from 30 to 60 feet in width. Towns which subsided several cubits, were overflowed with water; among others Deep Gong, which was submerged to the depth of 7 cubits. Two volcanos are said to have opened in the Secta Cunda hills. The shock was also felt at Calcutta.* While the Chittagong coast was sinking, a corresponding rise of the ground took place at the island of Ramree, and at Cheduba. (See Map, fig. 65, Vol. I. p. 587.)†

Earthquake of Lisbon, 1755.—*Extent of the shock.*—In no part of the volcanic region of southern Europe has so tremendous an earthquake occurred in modern times as that which began on November 1, 1755, at Lisbon. The inhabitants had had no warning of the coming danger, when a sound like that of thunder was heard underground, and immediately afterwards a violent shock threw down the greater part of their city. In the course of about six minutes 60,000 persons perished. The sea first retired and laid the bar dry; it then rolled in, rising 50 feet or more above its ordinary level. The mountains of Arrabida, Estrella, Julio, Marvan, and Cintra, being some of the largest in Portugal, were impetuously shaken, as it were, from their very foundations; and some of them opened at their summits, which were split and rent in a wonderful manner, huge masses of them being thrown down into the subjacent valleys.‡ Flames are related to have issued from these mountains, which are supposed to have been electric; they are also said to have smoked; but vast clouds of dust may have given rise to this appearance.

Subsidence of the quay.—Among other extraordinary events related to have occurred at Lisbon during the catastrophe, was the subsidence of a new quay, built entirely of marble at an immense expense. A great concourse of people had collected there for safety, as a spot where they might be beyond the reach of falling ruins; but suddenly the quay

* M'Clelland's Report on Min. Resources of India, 1838. Calcutta. For other particulars, see Phil. Trans. vol. liii.

† Journ. Asiat. Soc. Bengal, vol. x. pp. 351, 433.

‡ Hist. and Philos. of Earthquakes, p. 317.

sank down with all the people on it, and not one of the dead bodies ever floated to the surface. A great number of boats and small vessels anchored near it, all full of people, were swallowed up, as in a whirlpool.* No fragments of these wrecks ever rose again to the surface, and the water in the place where the quay had stood is stated, in many accounts, to be unfathomable; but Whitehurst says he ascertained it to be 100 fathoms.†

Circumstantial as are the contemporary narratives, I was informed by Mr. F. Freeman, in 1841, that no part of the Tagus was then more than 30 feet deep at high tide, and an examination of the position of the new quay, and the memorials preserved of the time and manner in which it was built, render the statement of so great a subsidence in 1755 quite unintelligible. Perhaps a deep narrow chasm, such as was before described in Calabria (p. 125), opened and closed again in the bed of the Tagus, after swallowing up some vessels and adjoining buildings. We have already seen that such openings may collapse after the shock suddenly, or in places where the strata are of soft and yielding materials, very gradually. According to the observations made at Lisbon, in 1837, by Mr. Sharpe, the destroying effects of this earthquake were confined to the tertiary strata, and were most violent on the blue clay, on which the lower part of the city is constructed. Not a building, he says, on the secondary limestone or the basalt was injured.‡

The area over which this convulsion extended is very remarkable. It has been computed, says Humboldt,§ that on November 1, 1755, a portion of the earth's surface four times greater than the extent of Europe was simultaneously shaken. The shock was felt in the Alps, and on the coast of Sweden, in small inland lakes on the shores of the Baltic, in Thuringia, in the flat country of northern Germany, and in

* Rev. C. Davy's Letters, vol. ii. Letter ii. p. 12. He was at Lisbon at the time, and ascertained that the boats and vessels said to have been swallowed were missing.

† On the Formation of the Earth, p. 55.

‡ Proc. Geol. Soc. No. 60, p. 36. 1838.

§ Cosmos, vol. i.

Great Britain. The thermal springs of Töplitz dried up, and again returned, inundating everything with water discoloured by ochre. In the islands of Antigua, Barbadoes, and Martinique in the West Indies, where the tide usually rises little more than 2 feet, it suddenly rose above 20 feet, the water being discoloured and of an inky blackness. The movement was also sensible in the great lakes of Canada. At Algiers and Fez, in the north of Africa, the agitation of the earth was as violent as in Spain and Portugal; and at the distance of 8 leagues from Morocco, a village with the inhabitants, to the number of about 8,000 or 10,000 persons, is said to have been swallowed up; the earth soon afterwards closing over them.

Shocks felt at sea.—The shock was felt at sea, on the deck of a ship to the west of Lisbon, and produced very much the same sensation as on dry land. Off St. Lucar, the captain of the ship 'Nancy' felt his vessel so violently shaken, that he thought she had struck the ground; but, on heaving the lead, found a great depth of water. Captain Clark, off Denia, on the east coast of Spain, in latitude 36° 24′ N., between 9 and 10 in the morning, had his ship shaken and strained as if she had struck upon a rock, so that the seams of the deck opened, and the compass was overturned in the binnacle. Another ship, 40 leagues west of St. Vincent, experienced so violent a concussion, that the men were thrown a foot and a half perpendicularly up from the deck.

Rate at which the movement travelled.—The agitation of lakes, rivers, and springs, in Great Britain, was remarkable. At Loch Lomond, in Scotland, for example, the water, without the least apparent cause, rose against its banks, and then subsided below its usual level. This is explained by supposing that the water does not partake of the sudden shove given to the land, so that it dashes over that side of the basin from which the shock is given. The greatest vertical height of the rise in Loch Lomond was 2 feet 4 inches. It is said that the undulatory movement of this earthquake travelled at the rate of 20 miles a minute, its velocity being calculated by the intervals between the time when the first

shock was felt at Lisbon, and its time of occurrence at several distant places.*

Great wave and retreat of the sea.—A great wave swept over the coast of Spain, and is said to have been 60 feet high at Cadiz. At Tangier, in Africa, it rose and fell 18 times on the coast. At Funchal, in Madeira, it rose full 15 feet perpendicular above high-water mark, although the tide, which ebbs and flows there 7 feet, was then at half ebb. Besides entering the city, and committing great havoc, it overflowed other seaports in the island. At Kinsale, in Ireland, a body of water rushed into the harbour, whirled round several vessels, and poured into the market-place.

It was before stated that the sea first retired at Lisbon; and this retreat of the ocean from the shore, at the commencement of an earthquake, and its subsequent return in a violent wave, is a common occurrence. In order to account for the phenomenon, Michell (see Vol. I. p. 61) imagined a subsidence at the bottom of the sea, from the giving way of the roof of some cavity in consequence of a vacuum produced by the condensation of steam. Such condensation, he observes, might be the first effect of the introduction of a large body of water into fissures and cavities already filled with steam, before there has been sufficient time for the heat of the incandescent lava to turn so large a supply of water into steam, which being soon accomplished causes a greater explosion.

Another proposed explanation is, the sudden rise of the land, which would cause the sea to abandon immediately the ancient line of coast; and if the shore, after being thus heaved up, should fall again to its original level, the ocean would return. This theory, however, will not account for the facts observed during the Lisbon earthquake; for the retreat preceded the wave, not only on the coast of Portugal, but also at the island of Madeira, and several other places. If the upheaving of the coast of Portugal had caused the retreat, the motion of the waters, when propagated to Madeira, would have produced a wave previous to the retreat.

The shock transmitted through the earth from Lisbon,

* Geol. Soc. Proceedings, No. 60, p. 36. 1838.

reached Madeira in 25 minutes, and the sea-wave took $2\frac{1}{2}$ hours to travel the same distance, which agrees well with the time which it required to reach other places according to their distance. We cannot, therefore, explain the great motion of the waters at Madeira by a momentary upward movement of the solid crust of the earth, for in that case the rise of the beach would have occurred at the first period or 25 minutes after the Lisbon shock; besides, it will be seen in the sequel, page 153, that where the sea is deep near the shore, and the beach very steep, as in Madeira, the land-wave cannot cause a retreat of the sea.

The following is another solution of the problem, which has been offered:—Suppose a portion of the bed of the sea to be suddenly upheaved; the first effect will be to raise over the elevated part a body of water, the momentum of which will carry it much above the level it will afterwards assume, causing a draught or receding of the water from the neighbouring coasts, followed immediately by the return of the displaced water, which will also be impelled by its momentum much farther and higher on the coast than its former level.*

Mr. Darwin, when alluding to similar waves on the coast of Chili, states his opinion, that 'the whole phenomenon is due to a common undulation in the water, proceeding from a line or point of disturbance some little way distant. If the waves,' he says, 'sent off from the paddles of a steam-vessel be watched breaking on the sloping shore of a still river, the water will be seen first to retire two or three feet, and then to return in little breakers, precisely analogous to those consequent on an earthquake. He also adds, that 'the earthquake-wave occurs some time after the shock, the water at first retiring both from the shores of the mainland and of outlying islands, and then returning in mountainous breakers. Their size is modified by the form of the neighbouring coast; for it is ascertained in South America, that places situated at the head of shoaling bays have suffered most, whereas towns like Valparaiso, seated close on the border of a profound

* Quarterly Review, No. lxxxvi. p. 459.

ocean, have never been inundated, though severely shaken by earthquakes.'*

More recently (February, 1846), Mr. Mallet, in his memoir above cited (p. 137), has endeavoured to bring to bear on this difficult subject the more advanced knowledge obtained of late years respecting the true theory of waves. He conceives that when the origin of the shock is beneath the deep ocean, one wave is propagated through the land, and another moving with inferior velocity is formed on the surface of the ocean. This last rolls in upon the land long after the earth-wave has arrived and spent itself. However irreconcilable it may be to our common notions of solid bodies, to imagine them capable of transmitting, with such extreme velocity, motions analogous to tidal waves, it seems nevertheless certain that such undulations are produced, and it is supposed that when the shock passes a given point, each particle of the solid earth describes part of an ellipse in space. The facility with which all the particles of a solid mass can be made to vibrate may be illustrated, says Gay-Lussac, by many familiar examples. If we apply the ear to one end of a long wooden beam, and listen attentively when the other end is struck by a pin's head, we hear the shock distinctly; which shows that every fibre throughout the whole length has been made to vibrate. The rattling of carriages on the pavement shakes the largest edifices; and in the quarries underneath some quarters in Paris, it is found that the movement is communicated through a considerable thickness of rock.†

The great sea-wave originating directly over the centre of disturbance is propagated, as Michell correctly stated, in every direction, like the circle upon a pond when a pebble is dropped into it, the different rates at which it moves depending (as he also suggested) on variations in the depth of the water. This wave of the sea, says Mr. Mallet, is raised by the impulse of the shock immediately below it, which in great earthquakes lifts up the ground 2 or 3 feet vertically. The velocity of the shock, or earth-wave, is greater because

* Darwin's Travels in South America, &c., 1832 to 1836. Voyage of H.M.S. Beagle, vol. iii. p. 377.

† Ann. de Ch. et de Ph. tom. xxii. p. 428.

it 'depends upon a function of the elasticity of the crust of the earth, whereas the velocity of the sea-wave depends upon a function of the depth of the sea.'

'Although the shock in its passage under the deep ocean gives no trace of its progress, it no sooner gets into soundings or shallow water, than it gives rise to another and smaller wave of the sea. It carries, as it were, upon its back, this lesser aqueous undulation; a long narrow ridge of water, which corresponds in form and velocity to itself, being pushed up by the partial elevation of the bottom. It is this small wave, called technically the "forced sea-wave," which communicates the earthquake-shock to ships at sea, as if they had struck upon a rock. It breaks upon a coast at the same moment that the shock reaches it, and sometimes it may cause an apparent slight recession from the shore, followed by its flowing up somewhat higher than the usual tide mark: this will happen where the beach is very sloping, as is usual where the sea is shallow, for then the velocity of the low flat earth-wave is such, that it slips, as it were, from under the undulation in the fluid above. It does this at the moment of reaching the beach, which it elevates by a vertical height equal to its own, and as instantly lets drop again to its former level.'

'While the shock propagated through the solid earth has thus travelled with extra rapidity to the land, the great sea-wave has been following at a slower pace, though advancing at the rate of several miles in a minute. It consists, in the deep ocean, of a long low swell of enormous volume, having an equal slope before and behind, and that so gentle that it might pass under a ship without being noticed. But when it reaches the edge of soundings, its front slope, like that of a tidal wave under similar circumstances, becomes short and steep, while its rear slope is long and gentle. If there be water of some depth close into shore, this great wave may roll in long after the shock, and do little damage: but if the shore be shelving, there will be first a retreat of the water, and then the wave will break upon the beach and roll in far upon the land.'*

* Mallet, Proceed. Roy. Irish Acad. 1846.

The various opinions which have been offered by Michell and later writers, respecting the remote causes of earthquake shocks in the interior of the earth, will more properly be discussed in Chapter XXXIII.

Chili, 1751.—On May 24, 1751, the ancient town of Conception, otherwise called Penco, was totally destroyed by an earthquake, and the sea rolled over it. (See plan of the bay, fig. 110, p. 92.) The ancient port was rendered entirely useless, and the inhabitants built another town about 10 miles from the sea-coast, in order to be beyond the reach of similar inundations. At the same time, a colony recently settled on the sea-shore of Juan Fernandez, 365 miles distant from Penco, was almost entirely overwhelmed by a wave which broke upon the shore.

It has been already stated, that in 1835, or 84 years after the destruction of Penco, the same coast was overwhelmed by a similar flood from the sea during an earthquake; and it is also known that 21 years before (or in 1730), a like wave rolled over these fated shores, in which many of the inhabitants perished. A series of similar catastrophes has also been tracked back as far as the year 1590,* beyond which we have no memorials save those of oral tradition. Molina, who has recorded the customs and legends of the aborigines, tells us, that the Araucanian Indians, a tribe inhabiting the country between the Andes and the Pacific, including the part now called Chili, 'had among them a tradition of a great deluge, in which only a few persons were saved, who took refuge upon a high mountain called Thegtheg, "the thundering," which had three points.' Whenever a violent earthquake occurs, these people fly for safety to the mountains, assigning as a reason, that they are fearful, after the shock, that the sea will again return and deluge the world.†

Notwithstanding the tendency of writers in his day to refer all traditionary inundations to one remote period, Molina remarks that this flood of the Araucanians 'was probably very different from that of Noah.' We have, indeed, no means of conjecturing how long this same tribe

* See Father Acosta's work; and Sir Woodbine Parish, Geol. Soc. Proceedings, vol. ii. p. 215.

† Molina, Hist. of Chili, vol. ii.

had flourished in Chili, but we can scarcely doubt, that if its experience reached back even for three or four centuries, several inroads of the ocean must have occurred within that period. But the memory of a succession of physical events, similar in kind, though distinct in time, can never be preserved by a people destitute of written annals. Before two or three generations have passed away all dates are forgotten, and even the events themselves, unless they have given origin to some customs, or religious rites and ceremonies. Oftentimes the incidents of many different earthquakes and floods become blended together in the same narrative; and in such cases the single catastrophe is described in terms so exaggerated, or is so disguised by mythological fictions, as to be utterly valueless to the man of science.

Proofs of elevation of the coast.—During a late survey of Conception Bay, Captains Beechey and Sir E. Belcher discovered that the ancient harbour, which formerly admitted all large merchant vessels which went round Cape Horn, is now occupied by a reef of sandstone, certain points of which project above the sea at low water, the greater part being very shallow. A tract of 1½ mile in length, where, according to the report of the inhabitants, the water was formerly 4 or 5 fathoms deep, is now a shoal; consisting, as our hydrographers found, of hard sandstone, so that it cannot be supposed to have been formed by recent deposits of the river Biobio, an arm of which carries down loose micaceous sand into the same bay.

It is impossible at this distance of time to affirm that the bed of the sea was uplifted at once to the height of 24 feet, during the single earthquake of 1751, because other movements may have occurred subsequently; but it is said, that ever since the shock of 1751, no vessels have been able to approach within 1½ mile of the ancient port of Penco. (See Map, p. 92.) In proof of the former elevation of the coast near Penco, our surveyors found above high-water mark an enormous bed of shells of the same species as those now living in the bay, filled with micaceous sand like that which the Biobio now conveys to the bay. These shells, as well as others, which cover the adjoining hills of mica-schist

to the height of several hundred feet, have been examined by experienced conchologists, and identified with those taken at the same time in a living state from the bay and its neighbourhood.*

Ulloa, therefore, was perfectly correct in his statement that, at various heights above the sea between Talcahuano and Conception, 'mines were found of various sorts of shells used for lime of the very same kinds as those found in the adjoining sea.' Among them he mentions the great mussel called Choros, and two others which he describes. Some of these, he says, are entire, and others broken; they occur at the bottom of the sea, in 4, 6, 10, or 12 fathom water, where they adhere to a sea-plant called Cochayuyo. They are taken in dredges, and have no resemblance to those found on the shore or in shallow water; yet beds of them occur at various heights on the hills. 'I was the more pleased with the sight,' he adds, 'as it appeared to me a convincing proof of the universality of the deluge, although I am not ignorant that some have attributed their position to other causes.'† It has, however, been ascertained that the foundation of the Castle of Penco was so low in 1835, or at so inconsiderable an elevation above the highest spring tides, as to discountenance the idea of any permanent upheaval in modern times, on the site of that ancient port; but no exact measurements or levellings appear as yet to have been made to determine this point, which is the more worthy of investigation, because it may throw some light on an opinion often promulgated of late years, that there is a tendency in the Chilian coast, after each upheaval, to sink gradually and return towards its former position.

Peru, 1746.—Peru was visited, on October 28, 1746, by a tremendous earthquake. In the first 24 hours, 200 shocks were experienced. The ocean twice retired and returned impetuously upon the land: Lima was destroyed, and part of the coast near Callao was converted into a bay: 4 other harbours, among which were Cavalla and Guanape, shared

* Captain Belcher showed me these shells, and the collection was examined by Mr. Broderip.

† Ulloa's Voyage to South America, vol. ii. book viii. ch. vi.

the same fate. There were 23 ships and vessels, great and small, in the harbour of Callao, of which 19 were sunk; and the other 4, among which was a frigate called 'St. Fermin,' were carried by the force of the waves to a great distance up the country, and left on dry ground at a considerable height above the sea. The number of inhabitants in this city amounted to 4,000. 200 only escaped, 22 of whom were saved on a small fragment of the fort of Vera Cruz, which remained as the only memorial of the town after this dreadful inundation. Other portions of its site were completely covered with heaps of sand and gravel.

A volcano in Lucanas burst forth the same night, and such quantities of water descended from the cone that the whole country was overflowed; and in the mountain near Pataz, called Conversiones de Caxamarquilla, three other volcanos burst out, and frightful torrents of water swept down their sides.*

There are several records of prior convulsions in Peru, accompanied by similar inroads of the sea, one of which happened 59 years before (in 1687), when the ocean, according to Ulloa, first retired and then returned in a mountainous wave, overwhelming Callao and its environs, with the miserable inhabitants.† This same wave, according to Lionel Wafer, carried ships a league into the country, and drowned man and beast for 50 leagues along the shore.‡ Inundations of still earlier dates are carefully recorded by Ulloa, Wafer, Acosta, and various writers, who describe them as having expended their chief fury some on one part of the coast, some on another.

But all authentic accounts cease when we ascend to the era of the conquest of Peru by the Spaniards. The ancient Peruvians, although far removed from barbarism, were without written annals, and therefore unable to preserve a distinct recollection of a long series of natural events. They had, however, according to Antonio de Herrera, who, in the beginning of the 17th century, investigated their antiquities,

* Ulloa's Voyage to South America, vol. ii. book vii. ch. vii.

† Ibid. vol. ii. p. 82.

‡ Wafer, cited by Sir W. Parish, Geol. Soc. Proceedings, vol. ii. p. 215.

a tradition, 'that many years before the reign of the Incas, at a time when the country was very populous, there happened a great flood; the sea breaking out beyond its bounds, so that the land was covered with water and all the people perished. To this the Guacas, inhabiting the vale of Xausca, and the natives of Chiquito, in the province of Callao, add that some persons remained in the hollows and caves of the highest mountains, who again peopled the land. Others of the mountain people affirm that all perished in the deluge, only 6 persons being saved on a float, from whom descended all the inhabitants of that country.'*

On the mainland near Lima, and on the neighbouring island of San Lorenzo, Mr. Darwin found proofs that the ancient bed of the sea had been raised to the height of more than 80 feet above water within the human epoch, strata having been discovered at that altitude, containing pieces of cotton thread and plaited rush, together with sea-weed and marine shells.† The same author learnt from Mr. Gill, a civil engineer, that he discovered in the interior near Lima, between Casma and Huaraz, the dried-up channel of a large river, sometimes worn through solid rock, which, instead of continually ascending towards its source, has, in one place, a steep downward slope in that direction, for a ridge or line of hills has been uplifted directly across the bed of the stream, which is now arched. By these changes the water has been turned into some other course; and a district, once fertile, and still covered with ruins, and bearing the marks of ancient cultivation, has been converted into a desert.‡

Java, 1699.—On January 5, 1699, a terrible earthquake visited Java, and no less than 208 considerable shocks were reckoned. Many houses in Batavia were overturned, and the flame and noise of a volcanic eruption were seen and heard in that city, which were afterwards found to proceed from Mount Salek,§ a volcano 6 days' journey distant. Next morning the Batavian river, which has its rise from that mountain, became very high and muddy, and brought

* Hist. of America, decad. iii. book xi. ch. i.

† Darwin's Journal, p. 451.

‡ Ibid. p. 413.

§ Misspelt 'Sales' in Hooke's Account.

down abundance of bushes and trees, half burnt. The channel of the river being stopped up, the water overflowed the country round the gardens about the town, and some of the streets, so that fishes lay dead in them. All the fish in the river, except the carp, were killed by the mud and turbid water. A great number of drowned buffaloes, tigers, rhinoceroses, deer, apes, and other wild beasts, were brought down by the current; and, 'notwithstanding,' observes one of the writers, 'that a crocodile is amphibious, several of them were found dead among the rest.'*

It is stated that seven hills bounding the river sank down; by which must be meant, as by similar expressions in the description of the Calabrian earthquakes, seven great landslips. These hills, descending some from one side of the valley and some from the other, filled the channel, and the waters then finding their way under the mass, flowed out thick and muddy. The Tangaran river was also dammed up by nine hills, and in its channel were large quantities of drift trees. Seven of its tributaries also are said to have been 'covered up with earth.' A high tract of forest land, between the two great rivers before mentioned, is described as having been changed into an open country, destitute of trees, the surface being spread over with a fine red clay. This part of the account may, perhaps, merely refer to the sliding down of woody tracts into the valleys, as happened to so many extensive vineyards and olive-grounds, in Calabria, in 1783. The close packing of large trees in the Batavian river is represented as very remarkable, and it attests in a striking manner the destruction of soil bordering the valleys which had been caused by floods and landslips.†

Quito, 1698.—In Quito, on the 19th of July, 1698, during an earthquake, a great part of the crater and summit of the volcano Carguairazo fell in, and a stream of water and mud issued from the broken sides of the hill.‡

Sicily, 1693.—Shocks of earthquakes spread over all Sicily in 1693, and on the 11th of January the city of Catania and 49 other places were levelled to the ground, and about

* Hooke's Posthumous Works, p. 437. 1705.

† Phil. Trans. 1700.

‡ Humboldt, Atl. Pit. p. 106.

100,000 people killed. The bottom of the sea, says Vicentino Bonajutus, sank down considerably, in the ports, inclosed bays, and open parts of the coast, and water bubbled up along the shores. Numerous long fissures of various breadths were caused, which threw out sulphurous water; and one of them, in the plain of Catania (the delta of the Simeto), at the distance of 4 miles from the sea, sent forth water as salt as the sea. The stone buildings of a street in the city of Noto, for the length of half a mile, sank into the ground, and remained hanging on one side. In another street, an opening large enough to swallow a man and horse appeared.*

Moluccas, 1693.—The small Isle of Sorea, which consists of one great volcano, was in eruption in the year 1693. Different parts of the cone fell, one after the other, into a deep crater, until almost half the space of the island was converted into a fiery lake. Most of the inhabitants fled to Banda; but great pieces of the mountain continued to fall down, so that the lake of lava became wider; and finally the whole population was compelled to emigrate. It is stated that, in proportion as the burning lake increased in size, the earthquakes were less vehement.†

Jamaica, 1692.—*Subsidence in the harbour.*—In the year 1692, the island of Jamaica was visited by a violent earthquake; the ground swelled and heaved like a rolling sea, and was traversed by numerous cracks, 200 or 300 of which were often seen at a time, opening and then closing rapidly again. Many people were swallowed up in these rents; some the earth caught by the middle, and squeezed to death; the heads of others only appeared above ground; and some were first engulphed, and then cast up again with great quantities of water. Such was the devastation, that even in Port Royal, then the capital, where more houses are said to have been left standing than in the whole island besides, three-quarters of the buildings, together with the ground they stood on, sank down with their inhabitants entirely under water.

The large store-house on the harbour side subsided, so as

* Phil. Trans. 1693-4.

† De la Bêche, Manual of Geol. p. 133, 2nd edition.

to be 24, 36, and 48 feet under water; yet many of them appear to have remained standing, for it is stated that, after the earthquake, the mast-heads of several ships wrecked in the harbour, together with the chimney-tops of houses, were just seen projecting above the waves. A tract of land round the town, about 1,000 acres in extent, sank down in less than one minute, during the first shock, and the sea immediately rolled in. The 'Swan' frigate, which was repairing in the wharf, was driven over the tops of many buildings, and then thrown upon one of the roofs, through which it broke. The breadth of one of the streets is said to have been doubled by the earthquake.

According to Sir H. de la Bêche, the part of Port Royal described as having sunk was built upon newly-formed land, consisting of sand, in which piles had been driven; and the *settlement* of this loose sand, charged with the weight of heavy houses, may, he suggests, have given rise to the subsidences alluded to.*

There have undoubtedly been instances in Calabria and elsewhere of slides of land on which the houses have still remained standing; and it is possible that such may have been the case at Port Royal. The fact at least of submergence is unquestionable, for I was informed by the late Admiral Sir Charles Hamilton that he frequently saw the submerged houses of Port Royal in the year 1780, in that part of the harbour which lies between the town and the usual anchorage of men-of-war. Bryan Edwards also says, in his History of the West Indies, that in 1793 the *ruins* were visible in clear weather from the boats which sailed over them.† Lastly, Lieutenant B. Jeffery, R.N., told me that, being engaged in a survey between the years 1824 and 1835, he repeatedly visited the site in question, where the depth of the water is from 4 to 6 fathoms, and whenever there was but little wind perceived distinct traces of houses. He saw these more clearly when he used the instrument called the 'diver's eye,' which is let down below the ripple of the wave.‡

* De la Bêche, Manual of Geol., p. 133, second edition.

† Vol. i. p. 235, 8vo. ed. 3 vols. 1801.

‡ Letter to the Author, May 1838.

At several thousand places in Jamaica the earth is related to have opened. On the north of the island, several plantations, with their inhabitants, were swallowed up, and a lake appeared in their place, covering about 1,000 acres, which afterwards dried up, leaving nothing but sand and gravel, without the least sign that there had ever been a house or a tree there. Several tenements at Yallows were buried under landslips; and one plantation was removed half-a-mile from its place, the crops continuing to grow upon it uninjured. Between Spanish Town and Sixteen-mile Walk, the high and perpendicular cliffs bounding the river fell in, stopped the passage of the river and flooded the latter place for 9 days, so that the people 'concluded it had been sunk as Port Royal was.' But the flood at length subsided, for the river had found some new passage at a great distance.

Mountains shattered.—The Blue Mountains and others are declared to have been strangely torn and rent. They appeared shattered and half-naked, no longer affording a fine green prospect, as before, but stripped of their woods and natural verdure. The rivers on these mountains first ceased to flow for about 24 hours, and then brought down into the sea, at Port Royal and other places, several hundred thousand tons of timber, which looked like floating islands on the ocean. The trees were in general barked, most of their branches having been torn off in the descent. It is particularly remarked in this, as in the narratives of so many other earthquakes, that fish were taken in great numbers on the coast during the shocks. The correspondents of Sir Hans Sloane, who collected with care the accounts of eye-witnesses of the catastrophe, refer constantly to *subsidences*, and some supposed the whole of Jamaica to have sunk down.*

Reflections on the amount of change since the close of the seventeenth century.—I have now enumerated some few only of the earthquakes of the last and present centuries, respecting which facts illustrative of geological enquiries are on record. Even if my limits permitted, it would be an unprofitable task to examine all the obscure and ambiguous narratives of

* Phil. Trans. 1694.

similar events of earlier epochs; although, if the places were now examined by geologists well practised in the art of interpreting the monuments of physical changes, many events which have happened within the historical era might doubtless be still determined with precision. It must not be imagined that, in the above sketch of the occurrences of a short period, I have given an account of all, or even the greater part, of the mutations which the earth has undergone by the agency of subterranean movements. Thus, for example, the earthquake of Aleppo, in the present century, and of Syria, in the middle of the 18th, would doubtless have afforded numerous phenomena, of great geological importance, had those catastrophes been described by scientific observers. The shocks in Syria in 1759 were protracted for three months, throughout a space of 10,000 square leagues: an area compared to which that of the Calabrian earthquake in 1783 was insignificant. Accon, Saphat, Balbeck, Damascus, Sidon, Tripoli, and many other places, were almost entirely levelled to the ground. Many thousands of the inhabitants perished in each; and, in the valley of Balbeck alone, 20,000 men are said to have been victims to the convulsion. In the absence of scientific accounts, it would be as irrelevant to our present purpose to enter into the details of such calamities, as to follow the track of an invading army, to enumerate the cities burnt or razed to the ground, and reckon the number of individuals who perished by famine or sword.

If such, then, be the amount of ascertained changes in less than two centuries, notwithstanding the extreme deficiency of our records during that brief period, how important must we presume the physical revolutions to have been in the course of 30 or 40 centuries, during which some countries habitually convulsed by earthquakes have been peopled by civilised nations! Towns engulphed during one earthquake may, by repeated shocks, have sunk to great depths beneath the surface, while the ruins remain as imperishable as the hardest rocks in which they are enclosed. Buildings and cities, submerged, for a time, beneath seas or lakes, and covered with sedimentary deposits, must, in some places, have been re-elevated to considerable heights above the level

of the ocean. The signs of these events have, probably, been rendered visible by subsequent mutations, as by the encroachments of the sea upon the coast, by deep excavations made by torrents and rivers, by the opening of new ravines, and chasms, and other effects of natural agents, so active in districts agitated by subterranean movements.

If it be asked why, if such wonderful monuments exist, so few have hitherto been brought to light, we reply—because they have not been searched for. In order to rescue from oblivion the memorials of former occurrences, the enquirer must know what he may reasonably expect to discover, and under what peculiar local circumstances. He must be acquainted with the action and effect of physical causes, in order to recognise, explain, and describe correctly the phenomena when they present themselves.

The best known of the great volcanic regions, of which the boundaries were sketched in Chapter XXII., is that which includes Southern Europe, Northern Africa, and Central Asia; yet nearly the whole, even of this region, must be laid down, in a geological map, as 'Terra Incognita,' for we are only beginning to know something of one small portion of it, viz. the district round Naples; and even here it is to recent antiquarian and geological research, not to history, that we are principally indebted for the information. I shall now proceed to lay before the reader some of the results of modern investigations in the Bay of Baiæ and the adjoining coast.

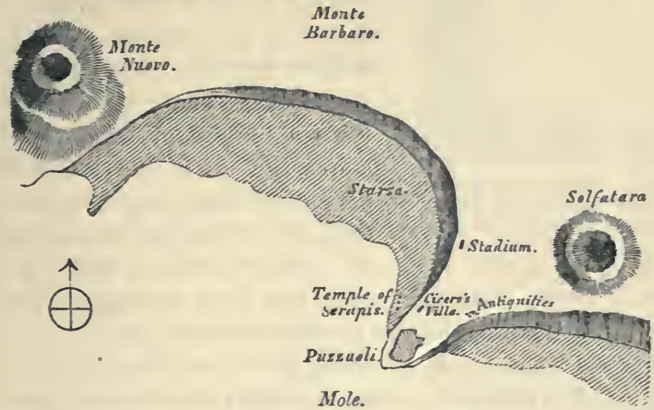
PROOFS OF ELEVATION AND SUBSIDENCE IN THE BAY OF BAIÆ.

Temple of Jupiter Serapis.—This celebrated monument of antiquity, a representation of which is given in the frontispiece * of this work (Vol. I.), affords in itself alone unequivocal evidence that the relative level of land and sea has changed twice at Puzzuoli since the beginning of the Christian

* The view of the Temple given in the frontispiece, Vol. I., has been reduced from part of a beautiful coloured drawing taken in 1836, with the aid of the camera lucida, by Mr. I'Anson, to illustrate a paper by Mr. Babbage on the Temple of Serapis, read March, 1834, and published in the Quart. Journ. of the Geol. Soc. of London, vol. iii. 1847.

era; and each movement, both of elevation and subsidence, has exceeded 20 feet. Before entering on these proofs, I may observe, that a geological examination of the coast of the Bay of Baiæ, both on the north and south of Puzzuoli,

Fig. 129.



Ground plan of the coast of the Bay of Baiæ, in the environs of Puzzuoli.

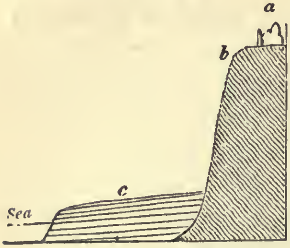
establishes in the most satisfactory manner an elevation, at no remote period, of more than 20 feet, and, at one point, of more than 30 feet; and the evidence of this change would have been complete, even if the temple had, to this day, remained undiscovered.

Coast south of Puzzuoli.—If we coast along the shore from Naples to Puzzuoli, we find on approaching the latter place that the lofty and precipitous cliffs of indurated tuff, resembling that of which Naples is built, retire slightly from the sea; and that a low level tract of fertile land, of a very different aspect, intervenes between the present sea-beach and what was evidently the ancient line of coast.

A portion of the inland cliff may be seen opposite the small island of Nisida, about 2½ miles south-east of Puzzuoli (see Map, fig. 66, Vol. I. p. 600), where, at the height of 32 feet above the level of the sea, Mr. Babbage observed an ancient mark, such as might have been worn by the waves; and, upon further examination, discovered that, along that line, the face of the perpendicular rock, consisting of very hard tuff, was covered with barnacles (*Balanus sulcatus*, Lamk.), and

drilled by boring testacea. Some of the hollows of the lithodomi contained the shells; while others were filled with the valves of a species of Arca.* Nearer to Puzzuoli, the inland cliff is 80 feet high, and as perpendicular as if it were still undermined by the waves. At its base, a new deposit, constituting the fertile tract above alluded to, attains a height of about 20 feet above the sea; and since it is composed of regular sedimentary deposits, containing marine shells, its position proves that, subsequently to its formation, there has been a change of more than 20 feet in the relative level of land and sea.

Fig. 130.



a. Antiquities on hill S.E. of Puzzuoli (see ground plan, fig. 129).
b. Ancient cliff, now inland.
c. Terrace composed of recent submarine deposit.

The sea encroaches on these new incoherent strata; and as the soil is valuable, a wall has been built for its protection; but when I first visited the spot in 1828, the waves had swept away part of this rampart, and exposed to view a regular series of strata of tuff, more or less argillaceous, alternating with beds of pumice and lapilli, and containing great abundance of marine shells, of species now common on this coast, and amongst them *Cardium rusticum*, *Ostrea edulis*, and *Donax trunculus*, Lamk. The strata vary from about a foot to a foot and a half in thickness, and one of them contains abundant remains of works of art, tiles, squares of mosaic pavement of different colours, and small sculptured ornaments, perfectly uninjured. Intermixed with these I collected some teeth of the pig and ox. These fragments of building occur below as well as above strata containing marine shells. Puzzuoli itself stands chiefly on a promontory of the older tufaceous formation, although I detected a small patch of the newer deposit remaining in a garden under the town.

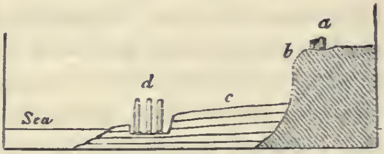
From the town the ruins of a mole, called Caligula's

* Mr. Babbage examined this spot in company with Sir Edmund Head in June 1828, and has shown me numerous specimens of the shells collected there, and in the Temple of Serapis.

Bridge, run out into the sea. (See No. 3, Frontispiece.)* This mole, which is believed to be eighteen centuries old, consists of a number of piers and arches, thirteen of which were standing in 1828, and two others appeared to have been overthrown. Mr. Babbage found, on the sixth pier, perforations of lithodomi four feet above the level of the sea; and, near the termination of the mole on the last pier but one, marks of the same, ten feet above the level of the sea, together with great numbers of balani and flustra. The depth of the sea, at a very small distance from most of the piers, is from 30 to 50 feet.

Coast north of Puzzuoli.—If we then pass to the north of Puzzuoli, and examine the coast between that town and Monte Nuovo, we find a repetition of analogous phenomena. The sloping sides of Monte Barbaro slant down within a short distance of the coast, and terminate in an inland cliff of moderate elevation, to which the geologist perceives at once that the sea must, at some former period, have extended.

Fig. 131.



a Remains of Cicero's villa, N. side of Puzzuoli.†
b. Ancient cliff now inland.
c. Terrace (called La Starza) composed of recent submarine deposits.
d. Temple of Serapis.

Between this cliff and the sea is the low plain or terrace, before alluded to, called La Starza (*c*, fig. 131), corresponding to that before described on the south-east of the town; and as the sea encroaches rapidly, fresh sections of the strata may readily be obtained, of which the annexed is an example.

Section on the shore north of the town of Puzzuoli.

	Ft.	In.
1. Vegetable soil	1	0
2. Horizontal beds of pumice and scoriæ, with broken fragments of unrolled bricks, bones of animals, and marine shells	1	6
3. Beds of lapilli, containing abundance of marine shells, principally *Cardium rusticum*, *Donax trunculus*, Lam., *Ostrea edulis*, *Triton cutaceum*, Lam., *Buccinum serratum*, Brocchi, the beds varying in thickness from one to eighteen inches	10	0
4. Argillaceous tuff, containing bricks and fragments of buildings not rounded by attrition	1	6

* This view is taken from Sir W. Hamilton, Campi Phlegræi, plate 26.

† This spot here indicated on the summit of the cliff is that from which

The thickness of many of these beds varies greatly as we trace them along the shore, and sometimes the whole group rises to a greater height than at the point above described. The surface of the tract which they compose appears to slope gently upwards towards the base of the old cliffs.

Now, if such appearances presented themselves on the coast of England, a geologist might endeavour to seek an explanation in some local change in the set of the tides and currents: but there are scarcely any tides in the Mediterranean; and, to suppose the sea to have sunk generally from twenty to twenty-five feet since the shores of Campania were covered with sumptuous buildings, is an hypothesis obviously untenable. The observations, indeed, made during modern surveys on the moles and cothons (docks) constructed by the ancients in various ports of the Mediterranean, have proved that there has been no sensible variation of level in that sea during the last two thousand years.*

Thus we arrive, without the aid of the celebrated temple, at the conclusion, that the recent marine deposit at Puzzuoli was upraised in modern times above the level of the sea, and that not only this change of position, but the accumulation of the modern strata, was posterior to the destruction of many edifices, of which they contain the embedded relics. If we next examine the evidence afforded by the temple itself, it appears, from the most authentic accounts, that the three pillars now standing erect continued, down to the middle of the last century, almost buried in the new marine strata (*c*, fig. 131). The upper part of each, protruding several feet above the surface, was concealed by bushes, and had not attracted, until the year 1749, the notice of antiquaries; but, when the soil was removed in 1750, they were seen to form part of the remains of a splendid edifice, the pavement of which was still preserved, and upon it lay a number of columns of African breccia and of granite. The original plan of the building could be traced distinctly: it was of a quadrangular form, 70 feet in diameter, and

Hamilton's view, plate 26, Campi Phlegræi (reduced in Plate VII.), is taken, and on which, he says, Cicero's villa, called the Academia, anciently stood.

* On the authority of the late Admiral Smyth, R.N.

the roof had been supported by 46 noble columns, 24 of granite, and the rest of marble. The large court was surrounded by apartments, supposed to have been used as bathing-rooms; for a thermal spring, still used for medicinal purposes, issues just behind the building, and the water of this spring appears to have been originally conveyed by a marble duct, still extant, into the chambers, and then across the pavement by a groove an inch or two deep, to a conduit made of Roman brickwork, by which it gained the sea.

Many antiquaries have entered into elaborate discussions as to the deity to which this edifice was consecrated. It is admitted that, among other images found in excavating the ruins, there was one of the god Serapis; and at Puzzuoli a marble column was dug up, on which was carved an ancient inscription, of the date 648 after the building of Rome (or B.C. 105), entitled 'Lex parieti faciundo.' This inscription, written in very obscure Latin, sets forth a contract, between the municipality of the town, and a company of builders who undertook to keep in repair certain public edifices, the Temple of Serapis being mentioned amongst the rest, and described as being near or towards the sea, 'ad mare vorsum.' Sir Edmund Head, after studying, in 1828, the topography and antiquities of this district, and the Greek, Roman, and Italian writers on the subject, informed me, that at Alexandria, on the Nile, the chief seat of the worship of Serapis, there was a Serapeum of the same form as this temple at Puzzuoli, and surrounded in like manner by chambers, in which the devotees were accustomed to pass the night, in the hope of receiving during sleep a revelation from the god, as to the nature and cure of their diseases. Hence it was very natural that the priests of Serapis, a pantheistic divinity, who, among other usurpations, had appropriated to himself the attributes of Esculapius, should regard the hot spring as a suitable appendage to the temple, although the original Serapeum of Alexandria could boast no such medicinal waters. Signor Carelli * and others, in objecting to these views, have insisted on the fact, that the worship of Serapis, which we

* Dissertazione sulla Sagra Architettura degli Antichi.

know prevailed at Rome in the days of Catullus (in the first century before Christ), was prohibited by the Roman Senate, during the reign of the Emperor Tiberius. But there is little doubt that, during the reigns of that Emperor's successors, the shrines of the Egyptian god were again thronged by zealous votaries; and in no place more so than at Puteoli (now Puzzuoli), one of the principal marts for the produce of Alexandria.

Without entering farther into an enquiry which is not strictly geological, I shall designate this valuable relic of antiquity by its generally received name, and proceed to consider the memorials of physical changes inscribed on the three standing columns in most legible characters by the hand of Nature. (See Frontispiece, Vol. I.) These pillars, which have been carved each out of a single block of marble, are 40 feet 3½ inches in height. A horizontal fissure nearly intersects one of the columns; the other two are entire. They are all slightly out of the perpendicular, inclining somewhat to the south-west, that is, towards the sea.* Their surface is smooth and uninjured to the height of about twelve feet above their pedestals. Above this is a zone, about nine feet in height, where the marble has been pierced by a species of marine perforating bivalve—*Lithodomus*, Cuv.† The holes of these animals are pear-shaped, the external opening being minute, and gradually increasing downwards. At the bottom of the cavities, many shells are still found, notwithstanding the great numbers that have been taken out by visitors; in many the valves of a species of arca, an animal which conceals itself in small hollows, occur. The perforations are so considerable in depth and size, that they manifest a long-continued abode of the lithodomi in the columns; for, as the inhabitant grows older and increases in size, it bores a larger cavity, to correspond with the increased magnitude of its shell. We must, consequently, infer a long-continued im-

* This appears from the measurement of Captain Basil Hall, R.N., Proceedings of Geol. Soc., No. 38, p. 114; see also Patchwork, by the same author, vol. iii. p. 158. The fact of the three standing columns having been each formed out of a single stone was first pointed out to me by Mr. James Hall, and is important, as helping to explain why they were not shaken down.

† *Modiola lithophaga*, Lam. *Mytilus lithophagus*, Linn.

mersion of the pillars in sea-water, at a time when the lowest part was covered up and protected by marine, fresh-water, and volcanic strata, afterwards to be described, and by the rubbish of buildings; the highest part, at the same time, projecting above the waters, and being consequently weathered, but not materially injured. (See fig. 132, p. 172.)

On the pavement of the temple lie some columns of marble, which are also perforated in certain parts; one, for example, to the length of 8 feet, while, for the length of 4 feet, it is uninjured. Several of these broken columns are eaten into, not only on the exterior, but on the cross fracture, and, on some of them, other marine animals (serpulæ, &c.) have fixed themselves.* All the granite pillars are untouched by lithodomi. The platform of the temple, which is not perfectly even, was, when I visited it in 1828, about one foot below high-water mark (for there are small tides in the Bay of Naples); and the sea, which was only 100 feet distant, soaked through the intervening soil. The upper part of the perforations, therefore, was at least 23 feet above high-water mark; and it is clear that the columns must have continued for a long time in an erect position, immersed in salt water, and then the submerged portion must have been upraised to the height of about 23 feet above the level of the sea.

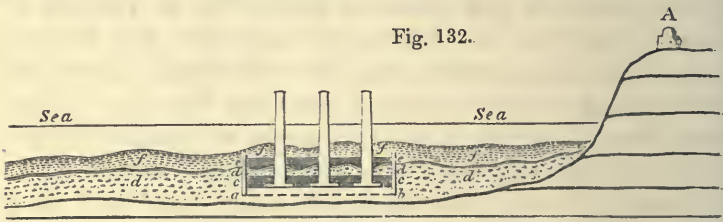
By excavations carried on in 1828, below the marble pavement on which the columns stand, another costly pavement of mosaic was found, at the depth of about 5 feet below the upper one (*a*, *b*, fig. 132). The existence of these two pavements, at different levels, clearly implies some subsidence previous to the building of the more modern temple which had rendered it necessary to construct the new floor at a higher level.

We have already seen (p. 169) that a temple of Serapis existed long before the Christian era. The change of level just mentioned must have taken place some time before the end of the second century, for inscriptions have been found in the temple, from which we learn that Septimius Severus

* *Serpula contortuplicata*, Linn., and *Vermilia triquetra*, Lam. These species, as well as the *Lithodomus*, are now inhabitants of the neighbouring sea.

adorned its walls with precious marbles between the years 194 and 211 of our era, and the Emperor Alexander Severus displayed the like munificence between the years 222 and 235.* From that era there is an entire dearth of historical information for a period of more than twelve centuries, except the significant fact that Alaric and his Goths sacked Puzzuoli in 410, and that Genseric did the like in 445, A.D. Yet we have fortunately a series of natural archives self-registered during the dark ages, by which many events which occurred in and about the temple are revealed to us. These natural records consist partly of deposits, which envelop the pillars below the zone of lithodomous perforations, and partly of those which surround the outer walls of the temple. Mr. Babbage, after a minute examination of these, has shown (see p. 164, note) that incrustations on the walls of the

Fig. 132.



Temple of Serapis at its period of greatest depression.

a b. Ancient mosaic pavement.
c c. Dark marine incrustation.
d d. First filling up, shower of ashes.
e e. Freshwater calcareous deposits.
f f. Second filling up.
A. Stadium.

exterior chambers and on the floor of the building demonstrate that the pavement did not sink down suddenly, but was depressed by a gradual movement. The sea first entered the court or atrium, and mingled its waters partially with those of the hot spring. From this brackish medium a dark calcareous precipitate (*c c*, fig. 132) was thrown down, which became, in the course of time, more than two feet thick, including some serpulæ in it. The presence of these annelids teaches us that the water was salt or brackish. After this period the temple was filled up with an irregular mass of volcanic tuff (*d d*, fig. 132), probably derived from an eruption of the neighbouring crater of the Solfatara, to the

* Brieslak, Voy. dans la Campanie, tom. ii. p. 167.

height of from 5 to 9 feet above the pavement. Over this again a purely freshwater deposit of carbonate of lime (*e e*, fig. 132) accumulated with an *uneven* bottom, since it necessarily accommodated itself to the irregular outline of the upper surface of the volcanic shower before thrown down. The top of the same deposit (a freshwater limestone) was perfectly even and flat, bespeaking an ancient water level. It is suggested by Mr. Babbage that this freshwater lake may have been caused by the fall of ashes which choked up the channel previously communicating with the sea, so that the hot spring threw down calcareous matter in the atrium without any marine intermixture. To the freshwater limestone succeeded another irregular mass of volcanic ashes and rubbish (*f f*, fig. 132), some of it perhaps washed in by the waves of the sea during a storm, its surface rising to 10 or 11 feet above the pavement. And thus we arrive at the period of greatest depression expressed in the accompanying diagram, when the lower half of the pillars was enveloped in the deposits above enumerated, and the uppermost 20 feet were exposed in the atmosphere, the remaining or middle portion, about 9 feet long, being for years immersed in salt water and drilled by perforating bivalves. After this period other strata, consisting of showers of volcanic ashes and materials washed in during storms, covered up the pillars to the height in some places of 35 feet above the pavement. The exact time when these enveloping masses were heaped up, and how much of them was formed during submergence, and how much after the re-elevation of the temple, cannot be made out with certainty.

The period of deep submergence was certainly antecedent to the close of the 15th century. Professor James Forbes* has reminded us of a passage in an old Italian writer, Loffredo, who says that in 1530, or 50 years before he wrote, which was in 1580, the sea washed the base of the hills which rise from the flat land called La Starza, as represented in fig. 132; so that, to quote his words, 'a person might then have fished from the site of those ruins which are now called the stadium' (A, fig. 132).

* Ed. Journ. of Science, New Series, No. II. p. 281.

But we know from other evidence that the upward movement had begun before 1530, for the Canonico Andrea di Jorio cites two authentic documents in illustration of this point. The first, dated Oct. 1503, is a deed written in Italian, by which Ferdinand and Isabella grant to the University of Puzzuoli a portion of land, 'where the sea is drying up' (che va seccando el mare); the second, a document in Latin, dated May 23, 1511, or nearly 8 years after, by which Ferdinand grants to the city a certain territory around Puzzuoli, where the ground *is dried up* (desiccatum).*

The principal elevation, however, of the low tract unquestionably took place at the time of the great eruption of Montè Nuovo in 1538. That event and the earthquakes which preceded it have been already described (Vol. I. p. 610); and we have seen that two of the eye-witnesses of the convulsion, Falconi and Giacomo di Toledo, agree in declaring that the sea abandoned a considerable tract of the shore, so that fish were taken by the inhabitants; and, among other things, Falconi mentions that he saw two springs *in the newly discovered ruins.*

The flat land, when first upraised, must have been more extensive than now, for the sea encroaches somewhat rapidly both to the north and south-east of Puzzuoli. The coast had, when I examined it in 1828, given way more than a foot in a twelvemonth; and I was assured, by fishermen in the bay, that it has lost ground near Puzzuoli, to the extent of 30 feet, within their memory.

It is, moreover, very probable that the land rose to a greater height at first, before it ceased to move upwards, than the level at which it was observed to stand when the temple was re-discovered in 1749, for we learn from a memoir of Niccolini, published in 1838, that since the beginning of the 19th century, the temple of Serapis has subsided more than 2 feet. That learned architect visited the ruins frequently, for the sake of making drawings, in the beginning of the year 1807, and was in the habit of remaining there throughout the day, yet never saw the pavement overflowed by the

* Sul Tempio di Serap. ch. viii.

sea, except occasionally when the south wind blew violently. On his return, 16 years after, to superintend some excavations ordered by the King of Naples, he found the pavement covered by sea-water, twice every day at high tide, so that he was obliged to place there a line of stones to stand upon. This induced him to make a series of observations from Oct. 1822 to July 1838, by which means he ascertained that the ground had been and was sinking, at the average rate of about 7 millimetres a year, or about 1 inch in 4 years; so that, in 1838, fish were caught every day on that part of the pavement where, in 1807, there was never a drop of water in calm weather.*

Mr. Smith, of Jordan Hill, examined the temple in 1847, and came to the conclusion from a comparison of various data that the rate of subsidence at that period was one inch annually.† Signor Scacchi, in 1852, after an examination undertaken by him at my request, inferred that the downward movement had ceased for several years, or had at least become almost inappreciable. I myself made several observations in 1857 and 1858, and came to the conclusion that there was a depth of about 2 feet of water on the pavement near the bronze ring on calm days at high tide when the Bay of Baiæ was not raised above its ordinary level by the wind. Although it would require a long series of measurements to obtain the exact average height of the tide in the bay, I cannot doubt that the relative level of the pavement and the sea has altered very sensibly since Niccolini first frequented the place.

From what was said before (p. 167), we saw that the marine shells in the strata forming the plain called La Starza, considered separately, establish the fact of an upheaval of the ground to the height of 23 feet and upwards. The temple proves much more, because it could not have been built originally under water, and must therefore first have sunk down 20 feet at least below the waves, to be afterwards restored to its original position. Yet if such was the order of events, we ought to meet with other independent

* Tavola Metrica Chronologica, &c. Napoli, 1838.

† Quart. Journ. Geol. Soc. vol. iii. p. 237.

signs of a like subsidence round the margin of a bay once so studded with buildings as the Bay of Baiæ. Accordingly memorials of such submergence are not wanting. About a mile N.W. of the temple of Serapis, and about 500 feet from the shore, are the ruins of a temple of Neptune and others of a temple of the Nymphs, now under water. The columns of the former edifice stand erect in five feet of water, their upper portions just rising to the surface of the sea. The pedestals are doubtless buried in the sand or mud; so that, if this part of the bottom of the bay should hereafter be elevated, the exhumation of these temples might take place after the manner of that of Serapis. Both these buildings probably participated in the movement which raised the Starza; but either they were deeper under water than the temple of Serapis, or they were not raised up again to so great a height. There are also two Roman roads under water in the bay, one reaching from Puzzuoli to the Lucrine Lake, which may still be seen, and the other near the castle of Baiæ (No. 8, Frontispiece). The ancient mole, too, of Puzzuoli (No. 4, ibid.), before alluded to, has the water up to a considerable height of the arches; whereas Brieslak justly observes, it is next to certain that the piers must formerly have reached the surface before the springing of the arches;* so that, although the phenomena before described proves that this mole has been uplifted 10 feet above the level at which it once stood, it is still evident that it has not yet been restored to its original position.

A modern writer also reminds us, that these effects are not so local as some would have us to believe; for on the opposite side of the Bay of Naples, on the Sorrentine coast, which, as well as Puzzuoli, is subject to earthquakes, a road with fragments of Roman buildings, is covered to some depth by the sea. In the island of Capri, also, which is situated some way out at sea, in the opening of the Bay of Naples, one of the palaces of Tiberius is now covered with water.†

* Voy. dans la Campanie, tome ii. p. 162.

† Mr. Forbes, Physical Notices of the Bay of Naples. Ed. Journ. of Sci., No. II., New Series, p. 280. October 1829. When I visited Puzzuoli, and arrived at the above conclusions, I knew nothing of Mr. Forbes's observations, which I first saw on my return to England the year following.

That buildings should have been submerged, and afterwards upheaved, without being entirely reduced to a heap of ruins, will appear no anomaly, when we recollect that, in the year 1819, when the delta of the Indus sank down, the houses within the fort of Sindree subsided beneath the waves without being overthrown (p. 102). In like manner, in the year 1692, the buildings around the harbour of Port Royal, in Jamaica, descended suddenly to the depth of between 30 and 50 feet under the sea without falling (p. 160). Even on small portions of land transported to a distance of a mile down a declivity, tenements, like those near Mileto, in Calabria, were carried entire. At Valparaiso buildings were left standing in 1822, when their foundations, together with a long tract of the Chilian coast, were permanently upraised to the height of several feet (p. 94). It is still more easy to conceive that an edifice may escape falling during the upheaval or subsidence of land, if the walls are supported on the exterior and interior with a deposit like that which surrounded and filled to the height of 10 or 11 feet the temple of Serapis all the time it was sinking, and which enveloped it to more than twice that height when it was rising again to its original level.

We can scarcely avoid the conclusion, as Mr. Babbage has hinted, 'that the action of heat is in some way or other the cause of the phenomenon of the change of level of the temple. Its own hot spring, its immediate contiguity to the Solfatara, its nearness to the Monte Nuovo, the hot spring at the baths of Nero (No. 6, Frontispiece), on the opposite side of the Bay of Baiæ; the boiling springs and ancient volcanos of Ischia on one side and Vesuvius on the other, are the most prominent of a multitude of facts which point to that conclusion.'* And when we reflect on the dates of the principal oscillations of level, and the volcanic history of the country before described (Chapter XXIV.), we seem to discover a connection between each era of upheaval and a local developement of volcanic heat, and again between each era of depression and the local quiescence or dormant condition of the subterranean igneous causes. Thus, for example, before

* Quart. Journ. Geol. Soc. 1847, vol. iii. p. 203.

the Christian era, when so many vents were in frequent eruption in Ischia, and when Avernus and other points in the Phlegræan Fields were celebrated for their volcanic aspect and character, the ground on which the temple stood was several feet above water. Vesuvius was then regarded as a spent volcano; but when, after the Christian era, the fires of that mountain were rekindled, scarcely a single outburst was ever witnessed in Ischia, or around the Bay of Baiæ. Then the temple was sinking. Vesuvius, at a subsequent period, became nearly dormant for five centuries preceding the great outbreak of 1631 (see Vol. I. p. 619), and in that interval the Solfatara was in eruption A.D. 1198, Ischia in 1302, and Monte Nuovo was formed in 1538. Then the foundations on which the temple stood were rising again. Lastly, Vesuvius once more became a most active vent, and has been so ever since, and during the same lapse of time the area of the temple, so far as we know anything of its history, has been subsiding.

These phenomena would agree well with the hypothesis, that when the subterranean heat is on the increase, and when lava is forming without obtaining an easy vent, like that afforded by a great habitual chimney such as Vesuvius, the incumbent surface is uplifted; but when the heated rocks below are cooling and contracting, and sheets of subterranean lava are slowly consolidating and diminishing in volume, then the incumbent land subsides.

Signor Nicolini, when he ascertained in 1838 that the relative levels of the floor of the temple and of the sea were slowly changing from year to year, embraced the opinion that it was the sea which was rising. But Signor Capocci successfully controverted this view, appealing to many appearances which attest the local character of the movements of the adjoining country, besides the historical fact that in 1538, when the sea retired permanently 200 yards from the ancient shore at Puzzuoli, there was no simultaneous retreat of the waters from Naples, Castelamare, and Ischia.*

Permanence of the ocean's level.—In concluding this subject, I may observe, that the interminable controversies to which

* Nuove Ricerche sul Temp. di Serap.

the phenomena of the Bay of Baiæ gave rise, have sprung from an extreme reluctance to admit that the land, rather than the sea, is subject alternately to rise and fall. Had it been assumed, as most probable, that the level of the ocean was invariable, on the ground that no fluctuations have as yet been clearly established, and that, on the other hand, the continents are inconstant in their level, as has been demonstrated by the most unequivocal proofs again and again, from the time of Strabo to our own times, the appearances of the temple at Puzzuoli could never have been regarded as enigmatical. Even if contemporary accounts had not distinctly attested the upraising of the coast, this explanation should have been proposed in the first instance as the most natural, instead of being now adopted unwillingly when all others have failed.

To the strong prejudices still existing in regard to the mobility of the land, we may attribute the rarity of such discoveries as have been recently brought to light in New Zealand, the Bay of Baiæ, and the Bay of Conception. A false theory, it is well known, may render us blind to facts which are opposed to our prepossessions, or may conceal from us their true import when we behold them. But it is time that the geologist should, in some degree, overcome those first and natural impressions which induced the poets of old to select the rock as the emblem of firmness—the sea as the image of inconstancy. Our modern poet, in a more philosophical spirit, saw in the sea 'the image of eternity,' and has finely contrasted the fleeting existence of the successive empires which have flourished and fallen on the borders of the ocean with its own unchanged stability.

> ——— Their decay
> Has dried up realms to deserts:—not so thou,
> Unchangeable, save to thy wild waves' play:
> Time writes no wrinkle on thine azure brow;
> Such as creation's dawn beheld, thou rollest now.
>
> CHILDE HAROLD, Canto iv.

CHAPTER XXXI.

ELEVATION AND SUBSIDENCE OF LAND WITHOUT EARTHQUAKES.

CHANGES IN THE RELATIVE LEVEL OF LAND AND SEA IN REGIONS NOT VOLCANIC—OPINION OF CELSIUS THAT THE WATERS OF THE BALTIC SEA AND NORTHERN OCEAN WERE SINKING—OBJECTIONS RAISED TO HIS OPINION—PROOFS OF THE STABILITY OF THE SEA LEVEL IN THE BALTIC—PLAYFAIR'S HYPOTHESIS THAT THE LAND WAS RISING IN SWEDEN—OPINION OF VON BUCH—MARKS CUT ON THE ROCKS—SURVEY OF THESE IN 1820—SIGNS OF OSCILLATIONS IN LEVEL—FISHING HUT BURIED UNDER MARINE STRATA—FACILITY OF APPRECIATING SLIGHT ALTERATIONS OF LEVEL ON THE INNER AND OUTER COAST OF SWEDEN—SUPPOSED MOVEMENT IN OPPOSITE DIRECTIONS IN PROCEEDING FROM THE NORTH CAPE SOUTHWARDS TO SCANIA—CHANGE OF LEVEL ON THE WEST COAST NEAR GOTHENBURG—GEOLOGICAL PROOFS OF THE GREAT OSCILLATION OF LEVEL SINCE THE GLACIAL PERIOD AT UDDEVALLA—UPRAISED MARINE DEPOSITS OF THE WESTERN COAST OF SWEDEN CONTAINING SHELLS OF THE OCEAN, THOSE ON THE EASTERN COAST SHELLS OF THE BALTIC—WHETHER NORWAY IS NOW RISING—MODERN SUBSIDENCE OF PART OF GREENLAND—PROOFS AFFORDED BY THESE MOVEMENTS OF GREAT SUBTERRANEAN CHANGES.

We have now considered the phenomena of volcanos and earthquakes according to the division of the subject before proposed (Vol. I. p. 577), and have next to turn our attention to those slow and insensible changes in the relative level of land and sea which take place in countries remote from volcanos, and where no violent earthquakes have occurred within the period of human observation. Early in the last century the Swedish naturalist, Celsius, expressed his opinion that the waters, both of the Baltic and Northern Ocean, were gradually subsiding. From numerous observations, he inferred that the rate of depression was about 40 Swedish inches in a century.* In support of this position, he alleged that there were many rocks both on the shores of the Baltic and the ocean known to have been once sunken reefs, and dangerous to navigators,

* The Swedish measure scarcely differs from ours; the foot being divided into twelve inches, and being less than ours by three-eighths of an inch only.

but which were in his time above water—that the waters of the Gulf of Bothnia had been gradually converted into land, several ancient ports having been changed into inland cities, small islands joined to the continent, and old fishing grounds deserted as being too shallow, or entirely dried up. Celsius also maintained, that the evidence of the change rested not only on modern observations, but on the authority of the ancient geographers, who had stated that Scandinavia was formerly an island. This island, he argued, must in the course of centuries, by the gradual retreat of the sea, have become connected with the continent; an event which he supposed to have happened after the time of Pliny, and before the ninth century of our era.

To this argument it was objected that the ancients were so ignorant of the geography of the most northern parts of Europe, that their authority was entitled to no weight; and that their representation of Scandinavia as an island, might with more propriety be adduced to prove the scantiness of their information, than to confirm so bold an hypothesis. It was also remarked, that if the land which connected Scandinavia with the main continent was laid dry between the time of Pliny and the ninth century, to the extent to which it is known to have stood above the sea at the latter period, the rate of depression of the sea could not have been uniform, as was pretended; for it ought to have fallen to a much greater extent in the longer interval between the 9th and 18th centuries, if the rate of movement had been the same.

Many of the proofs relied on by Celsius and his followers were immediately controverted by several philosophers, who saw clearly that a fall of the sea in any one region could not take place without a general sinking of the waters over the whole globe; they denied that this was the fact, or that the depression was universal, even in the Baltic. In proof of the stability of the level of that sea, they appealed to the position of the island of Saltholm, not far from Copenhagen. This island is so low, that in autumn and winter it is permanently overflowed; and it is only dry in summer, when it serves for pasturing cattle. It appears, from the documents of the year 1280, that Saltholm was then also in the same

state, and exactly on a level with the mean height of the sea, instead of having been about 20 feet under water, as it ought to have been, according to the computation of Celsius. Several towns, also, on the shores of the Baltic, at Lubeck, Wismar, Rostock, Stralsund, and others, after 600 and even 800 years, are as little elevated above the sea as at the era of their foundation, being now close to the water's edge. The lowest part of Dantzic was no higher than the mean level of the sea in the year 1000; and after 8 centuries its relative position remains exactly the same.*

Several of the examples of the gain of land and shallowing of the sea pointed out by Celsius, and afterwards by Linnæus, who embraced the same opinions, were ascribed by others to the deposition of sediment at points where rivers entered; and, undoubtedly, Celsius had not sufficiently distinguished between changes due to these causes and such as would arise if the waters of the ocean itself were diminishing. Many large rivers descending from a mountainous country, at the head of the Gulf of Bothnia, enter the sea charged with sand, mud, and pebbles; and it was said that in these places the low land had advanced rapidly, especially near Torneo. At Piteo also, ½ a mile had been gained in 45 years; at Luleo,† no less than 1 mile in 28 years; facts which might all be admitted consistently with the assumption that the level of the Baltic has remained unchanged, like that of the Adriatic, during a period when the plains of the Po and the Adige have greatly extended their area.

It was also alleged that certain insular rocks, once entirely covered with water, had at length protruded themselves above the waves, and grown, in the course of a century and a half, to be 8 feet high. The following attempt was made to explain away this phenomenon:—In the Baltic, large erratic blocks, as well as sand and smaller stones which lie on shoals, are liable every year to be frozen into the ice, where the sea freezes to the depth of 5 or 6 feet. On the melting of the snow in spring, when the sea rises about ½ a fathom, numerous

* For a full account of the Celsian controversy, we may refer our readers to Von Hoff, Geschichte, &c., vol. i. p. 439.

† Piteo and Luleo are spelt, in many English maps, Pitea and Lulea, but the *a* is not sounded in the Swedish diphthong å.

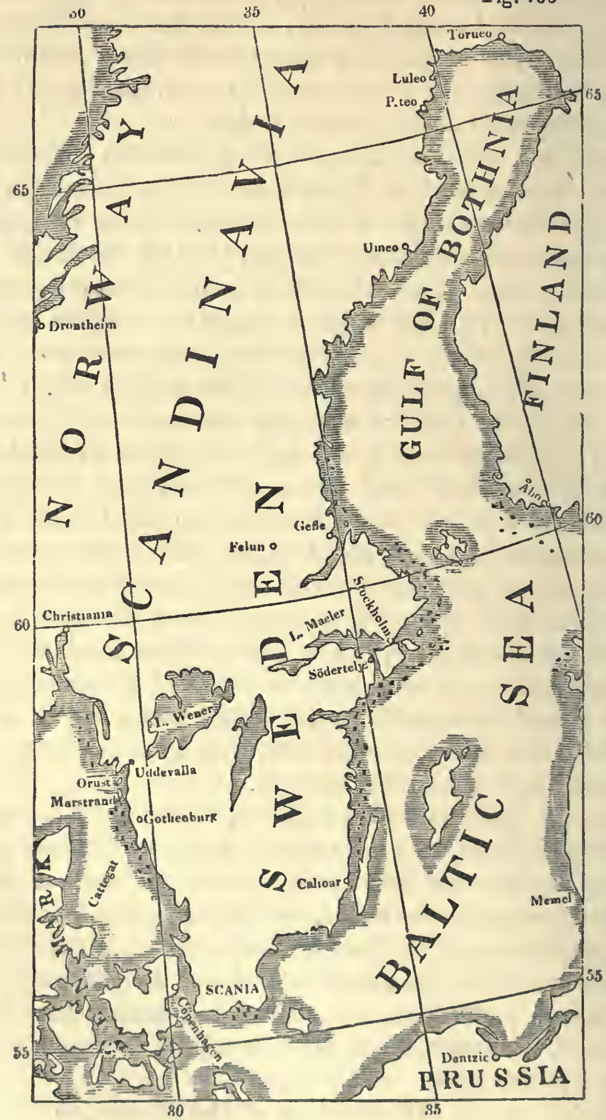
ice islands float away, bearing up these rocky fragments so as to convey them to a distance; and if they are driven by the waves upon shoals, they may convert them into islands by depositing the blocks; if stranded upon low islands, they may considerably augment their height.

Browallius, also, and some other Swedish naturalists, affirmed that some islands were lower than formerly; and that, by reference to this kind of evidence, there was equally good reason for contending that the level of the Baltic was gradually rising. They also added another curious proof of the permanency of the water level, at some points at least, for many centuries. On the Finland coast were some large pines and oaks, growing close to the water's edge; these were cut down, and, by counting the concentric rings of annual growth, as seen in a transverse section of the trunk, it was demonstrated that some of them had stood there for nearly 400 years. Now, according to the Celsian hypothesis, the sea had sunk about 15 feet during that period, in which case the germination and early growth of these trees must have been, for many seasons, below the level of the water. In like manner, it was asserted that the lower walls of many ancient castles, such as those of Sonderburg and Åbo, reached then to the water's edge, and must, therefore, according to the theory of Celsius, have been originally constructed below the level of the sea.

In reply to this last argument, Colonel Hällstrom, a Swedish engineer, well acquainted with the Finland coast, assured me, that the base of the walls of the castle of Abo is now ten feet above the water, so that there may have been a considerable rise of the land at that point since the building was erected. But the argument founded on the position of the trees is, as Professors Lovén and Erdmann have lately remarked, unanswerable so far as it relates to a part at least of the Finnish coast.

Playfair, in his 'Illustrations of the Huttonian Theory,' in 1802, admitted the sufficiency of the proofs adduced by Celsius, but attributed the change of level to the movement of the land, rather than to a diminution of the waters. He observed, 'that in order to depress or elevate the absolute

Fig. 133



level of the sea, by a given quantity, in any one place, we must depress or elevate it by the same quantity over the whole surface of the earth; whereas no such necessity exists

with respect to the elevation or depression of the land.'* The hypothesis of the rising of the land, he adds, 'agrees well with the Huttonian theory, which holds that our continents are subject to be acted upon by the expansive forces of the mineral regions; that by these forces they have been actually raised up, and are sustained by them in their present situation.'†

In the year 1807, Von Buch, after returning from a tour in Scandinavia, announced his conviction, 'that the whole country, from Fredrickshall in Norway to Åbo in Finland, and perhaps as far as St. Petersburg, was slowly and insensibly rising.' He also suggested 'that Sweden may rise more than Norway, and the northern more than the southern part.'‡ He was led to these conclusions principally by information obtained from the inhabitants and pilots respecting marks which had been set on the rocks, and partly by the occurrence of marine shells of recent species, which he had found at several points on the coast of Norway above the level of the sea. Von Buch, therefore, has the merit of being the first geologist who, after a personal examination of the evidence, declared in favour of the rise of land in Scandinavia.

The attention excited by this subject in the early part of the last century, had induced many philosophers in Sweden to endeavour to determine, by accurate observations, whether the standard level of the Baltic was really subject to periodical variations; and under their direction, lines or grooves, indicating the ordinary level of the water on a calm day, together with the date of the year, were chiselled out upon the rocks. In 1820–21, all the marks made before those years were examined by the officers of the pilotage establishment of Sweden; and in their report to the Royal Academy of Stockholm they declared, that on comparing the level of the sea at the time of their observations with that indicated by the ancient marks, they found that the Baltic was lower relatively to the land in certain places, but the amount of change during equal periods of time had not been everywhere

* Sect. 393. † Sect. 398. ‡ Transl. of his Travels, p. 387.

the same. During their survey, they cut new marks for the guidance of future observers, several of which I had an opportunity of examining fourteen years after (in the summer of 1834), and in that interval the land appeared to me to have risen at certain places north of Stockholm, as near Gefle, for example, about 4 inches, or at the rate of less than 2½ feet per century. But at Stockholm, I inferred from the position of certain aged oak-trees only 8 feet above the level of the Baltic, that the rise could not have been at a greater rate than 10 inches in a century, and might be less.* Professor Axel Erdmann in 1847 calculated that the rise could hardly have exceeded six inches at Stockholm, and in the same year he pointed out, in a paper read to the Royal Society of Sweden, the necessity of determining the mean level of the Baltic by a long series of observations in different seasons of the year. Mr. Wolfstedt, a Swedish engineer, has shown that the northern part of the Bothnian Gulf, where several great rivers enter, is 16 feet higher than the southern part; but as this gulf is about 600 miles in length, it will be seen that the rate of fall per mile according to this measurement is exceedingly small, so that the height of the water at corresponding seasons may vary but slightly, except when it is influenced by the wind. When I gave the results of my Swedish tour in the fourth edition of this work, published in 1835, I expressed my belief that there were signs of the upheaval of the land in different places visited by me, both on the coast of the Bothnian Gulf and on that of the ocean, i.e. the west coast of Sweden near Gothenburg. But I then stated that 'we have not only to learn whether the motion proceeds always at the same rate, but also whether it has been uniformly *in one direction.* The level of the land may oscillate; and for centuries there may be a depression, and afterwards a re-elevation, of the same district. Some phenomena in the neighbourhood of Stockholm appear to me only explicable on the supposition of the alternate rising and sinking of the ground since the country was inhabited by man. In digging a

* See a paper on 'Rise of Land in Sweden,' by the author. Phil. Trans. 1835, part i. p. 13—read in November 1834.

canal, in 1819, at Södertelje, about sixteen miles to the south of Stockholm, to unite Lake Maeler with the Baltic, marine strata, containing fossil shells of Baltic species, were passed through. At a depth of about 60 feet, they came down upon what seems to have been a buried fishing-hut, constructed of wood in a state of decomposition, which soon crumbled away on exposure to the air. The lowest part, however, which had stood on a level with the sea, was in a more perfect state of preservation. On the floor of this hut was a rude fireplace, consisting of a ring of stones, and within these were cinders and charred wood. On the outside lay boughs of the fir, cut as with an axe, with the leaves or needles still attached. It seems impossible to explain the position of this buried hut, without imagining, first, a subsidence to the depth of more than 60 feet, then a re-elevation. During the period of submergence, the hut must have become covered over with gravel and shelly marl, under which not only the hut, but several vessels also were found, of a very antique form, and having their timbers fastened together by wooden pegs instead of nails.' *

The investigations of MM. Lovén, Erdmann, Nordenskiöld, and others, made since my visit to Sweden in 1834, have on the whole tended to confirm the idea previously entertained, that some changes are now going on in the relative level of land and sea in certain parts of the Swedish coast, though they consider them to be probably local. With a view of accurately determining the reality of the movement, and its amount and direction, they have instituted a regular series of annual observations, which, however, have not yet been continued long enough to lead to positive results.

Lord Selkirk in 1866 re-examined many of the marks which I had seen, both in the Gulf of Bothnia and on the

* See my paper, before referred to, Phil. Trans. 1835, part i. pp. 8, 9. Attempts have been since made to explain away the position of this hut, by conjecturing that a more ancient trench had been previously dug here, which had become filled up in time by sand drifted by the wind. The engineers who superintended the works in 1819, and with whom I conversed, had considered every hypothesis of the kind, but could not so explain the facts.

Swedish coast near Gothenburg, in 1834. Among the former, the principal one, that of Löfgrund, near Gefle, seemed to indicate a fall of the water of about 9 inches in 32 years, which would give a rise of the land of between 2 and 3 feet in a century, as I had suggested; but other marks in the neighbourhood implied a smaller change of level. A line which I myself cut on a rock in the island of Gulholmen, off Oregrund, on the west coast, was found to be only 3 inches higher above the sea-level than when I made it. On the whole, after a comparison of this and various other marks, Lord Selkirk came to the conclusion, that, notwithstanding the absence of lunar tides both in the Baltic and on the west coast of Sweden near Gothenburg, there is so much fluctuation in the sea-level from day to day, owing to the action of the wind and other causes, that the observations of a casual visitor are of no real value in determining the average water-level.*

After a review of all that has been said and published on this subject since the commencement of the present century, I am inclined to believe, with the pilots, fishermen, and engineers, that a slow alteration in the relative level of land and sea is taking place along certain parts of the Swedish coast. This notion is not merely entertained by the inhabitants of those localities where rivers are carrying down sediment into the sea, but prevails equally in districts where the rocks for hundreds of miles plunge abruptly into deep water. It should be borne in mind, that, except near the Cattegat, there are no tides in the Baltic. It is only when particular winds have prevailed for several days in succession, or at certain seasons when there has been an unusually abundant influx of river-water, or when these causes have combined, that this sea is made to rise 2 or 3 feet above its standard level.

There are, moreover, peculiarities in the configuration of the shore which facilitate, in a remarkable degree, the appreciation of slight changes in the relative level of land and water. It has often been said, that there are two coasts,

* Lord Selkirk 'On some Sea-water Level Marks on the Coast of Sweden.' Quart. Geol. Journ. 1867, p. 187.

an inner and an outer one; the inner being the shore of the mainland; the outer one, a fringe of countless rocky islands of all dimensions, called the skär (*shair*). Boats and small vessels make their coasting voyages within this skär; for here they may sail in smooth water, even when the sea without is strongly agitated. But the navigation is very intricate, and the pilot must possess a perfect acquaintance with the breadth and depth of every narrow channel, and the position of innumerable sunken rocks. If on such a coast the land rises 1 or 2 feet in the course of half a century, the minute topography of the skär is entirely altered. To a stranger, indeed, who revisits it after an interval of many years, its general aspect remains the same; but the inhabitant finds that he can no longer penetrate with his boat through channels where he formerly passed, and he can tell of countless other changes in the height and breadth of isolated rocks, now exposed, but once only seen through the clear water.

The rocks of gneiss, mica-schist, and quartz are usually very hard on this coast, slow to decompose, and, when protected from the breakers, remain for ages unaltered in their form. Hence it is easy to mark the stages of their progressive emergence by the aid of natural and artificial marks imprinted on them. Besides the summits of *fixed* rocks, there are numerous erratic blocks of vast size strewed over the shoals and islands in the skär, which have been probably drifted by ice in the manner before suggested.* All these are observed to have increased in height and dimensions within the last half-century. Some, which were formerly known as dangerous sunken rocks, are now only hidden when the water is highest. On their first appearance, they usually present a smooth, bare, rounded protuberance, a few feet or yards in diameter; and a single sea-gull often appropriates to itself this resting-place, resorting there to devour its prey. Similar points, in the meantime, have grown into long reefs, and are constantly whitened by a multitude of sea-fowl; while others have been changed from a reef,

* See p. 182; and Chap. XVI. Vol. I.

annually submerged, to a small islet, on which a few lichens, a fir-seedling, and a few blades of grass, attest that the shoal has at length been fairly changed into dry land. Thousands of wooded islands around show the greater alterations which time can work. In the course of centuries, also, the spaces intervening between the existing islands may be laid dry, and become grassy plains, encircled by heights well clothed with lofty firs. This last step of the process, by which long fiords and narrow channels, once separating wooded islands, are deserted by the sea, has been exemplified within the memory of living witnesses on several parts of the coast.

It was admitted on all hands when I visited Sweden, in 1834, that the supposed change in the relative level of sea and land was by no means going on at a uniform rate, or in a uniform direction, at all points between the North Cape and Scania, or the southernmost part of Sweden, places distant from each other more than 1,000 miles. The rate of upheaval was said to be greatest at the North Cape, but no accurate scientific proof of this fact has yet been obtained. At Gefle, 90 miles north of Stockholm, the movement may possibly, as before stated, amount to 2 or 3 feet in a century, whereas at Stockholm it can hardly exceed 6 inches. 16 miles to the south-west of Stockholm, at Södertelje, the land seems to have been quite stationary during the last century. Proceeding still farther south, the upward movement seems to give place to one in an opposite direction. In proof of this fact, Professor Nilsson has remarked, in the first place, that there are no elevated beds of recent marine shells in Scania, like those farther to the north. Secondly, Linnæus, with a view of ascertaining whether the waters of the Baltic were retiring from the Scanian shore, measured in 1749, the distance between the sea and a large stone near Trelleborg. This same stone was, in 1836, a hundred feet nearer the water's edge than in Linnæus's time, or 87 years before. Thirdly, there is also a submerged peat moss, consisting of land and freshwater plants, beneath the sea at a point to which no peat could have been drifted down by any river. Fourthly, and what is still more conclusive, it is found that in seaport

towns, all along the coast of Scania, there are streets below the high-water level of the Baltic, and in some cases below the level of the lowest tide. Thus, when the wind is high at Malmö, the water overflows one of the present streets, and some years ago some excavations showed an ancient street in the same place 8 feet lower, and it was then seen that there had been an artificial raising of the ground, doubtless in consequence of that subsidence. There is also a street at Trelleborg, and another at Skanör, a few inches below high-water mark, and a street at Ystad is exactly on a level with the sea, at which it could not have been originally built.

When we cross from the Gulf of Bothnia to the coast north of Gothenburg, we find that the opinion still prevails there, as it did in the days of Celsius, among the fishing and seafaring inhabitants, that there is a slow sinking of the sea going on; so that rocks, both on the shore of the main-land and in the islands, are more and more exposed to view. If this conclusion be confirmed by future observation, the breadth of the tract from W.N.W. to E.S.E., which is rising, must exceed 200 geographical miles, without including the bed of the two seas adjacent to the coasts.

Hitherto we have confined our attention almost exclusively to changes of level in historical times; but we may next enquire what geological proofs exist of the sojourn of the sea on the land, at a very modern period, in those parts of Sweden where there is ground for suspecting that a movement of elevation is in progress.

In this case, the evidence is most satisfactory. Near Uddevalla and the neighbouring coastland, we find upraised deposits of shells belonging to species such as now live in the ocean; while on the opposite or eastern side of Sweden, near Stockholm, Gefle, and other places bordering the Bothnian Gulf, there are analogous beds containing shells of species characteristic of the Baltic.

Von Buch announced in 1807, that he had discovered in Norway and at Uddevalla in Sweden, beds of shells of existing species, at considerable heights above the sea. Since that time, other naturalists have confirmed his observation; and, according to Torell, deposits occur at

elevations of 600 and even 700 feet above the sea in some parts of Norway. M. Alex. Brongniart, when he visited Uddevalla, ascertained that one of the principal masses of shells, that of Capellbacken, is raised more than 200 feet above the sea, resting on rocks of gneiss, all the species being identical with those now inhabiting the contiguous ocean. The same naturalist also stated, that on examining with care the surface of the gneiss, immediately above the ancient shelly deposit, he found barnacles (*balani*) adhering to the rocks, showing that the sea had remained there for a long time. I was fortunate enough to be able to verify this observation by finding in the summer of 1834, at Kured, about 2 miles north of Uddevalla, and at the height of more than 100 feet above the sea, a surface of gneiss newly laid open by the partial removal of a mass of shells used largely in the district for making lime and repairing the roads. So firmly did these barnacles adhere to the gneiss, that I was able to break off portions of the rock with the shells attached. The face of the gneiss was also encrusted with bryozoa; but had these or the barnacles been exposed to the atmosphere ever since the elevation of the rocks above the sea, they would doubtless have been decomposed and obliterated.

The town of Uddevalla (see Map, p. 184) stands at the head of a narrow creek overhung by steep and barren rocks of gneiss, of which all the adjacent country is composed, except in the low grounds and bottoms of valleys, where strata of sand, clay, and marl frequently hide the fundamental rocks. To these newer and horizontal deposits, sometimes 40 feet thick, the fossil shells above mentioned belong, and similar marine remains are found at about the same height above the sea on the opposite island of Orust, as well as in that of Tjörn, and at points near the coast still farther south.

Mr. J. Gwyn Jeffreys visited Uddevalla in 1862, and collected from the beds there 83 species of mollusca, characteristic of the Glacial period. He also obtained evidence that a littoral and shallow-water deposit underlaid the shells proper to deeper water; a fact clearly implying a depression of the bed of the sea previous to that upheaval which has since carried

up the land where the marine shells are found, to the height of more than 200 feet.* As to the date of this last upheaval, Mr. Torell has shown that it by no means reaches back to the Glacial period, to which the shells above alluded to belong. Those shells, so characteristic of a cold climate, are specifically identical with mollusca now living in the seas of Spitzbergen, 10 degrees of latitude north of Uddevalla. But in some recent deposits near Uddevalla, Mr. Torell detected, at the height of 200 feet above the sea, the remains of marine testacea, agreeing with species now proper to the fauna of the adjacent and more temperate sea.† It appears, therefore, that the series of movements in the district under consideration consisted, first, of a depression converting the shallow water into deep sea at a time when the cold was very severe, and then of an elevation of more than 200 feet when the waters of the sea had acquired their present milder temperature.

To return now to the coast of the Baltic. I observed near the shores of the Gulf of Bothnia, at Södertelje, 16 miles S.W. of Stockholm, strata of sand, clay, and marl, more than 100 feet above the sea level, and containing shells of species now inhabiting the gulf. These consist partly of marine and partly of freshwater species; but though the individuals are numerous, the species are few in number, the brackish water appearing to be very unfavourable to the development of a rich and varied fauna. The most abundant species are the common cockle, mussel, and periwinkle of our shores (*Cardium edule*, *Mytilus edulis*, and *Littorina littorea*), together with a small tellina (*T. Baltica*, L.; *T. solidula*, Pult.), and a few minute univalves allied to *Paludina ulva*, which are still found living in that country associated with a *Lymnea*, a *Neritina* (*N. fluviatilis*), and some other freshwater shells.

But the marine mollusks of the Baltic above mentioned are dwarfish in size, scarcely ever attaining a third of the average dimensions which they acquire in the salter waters of the ocean. By this character alone a geologist would gene-

* Gwyn Jeffrey's Report to Brit Assoc. 1863, p. 73.

† Torell, Beiträge, &c. Contributions to Molluscous Fauna of Spitzbergen. 1859.

rally be able to recognise at once an assemblage of Baltic fossils as distinguished from those derived from a deposit in the ocean. The absence also of oysters, barnacles, whelks, scallops, limpets (*ostrea*, *balanus*, *buccinum*, *pecten*, *patella*), and many other forms abounding alike in the sea near Uddevalla, and in the fossiliferous deposits of modern date on that coast, supplies an additional negative character of the greatest value, distinguishing assemblages of Baltic from those of oceanic shells. Now the strata containing Baltic shells are found in many localities near Stockholm, Upsala, and Gefle, and will probably be discovered everywhere around the borders of the Bothnian Gulf; for I have seen similar remains brought from Finland, in marl resembling that found near Stockholm. The utmost distance to which these deposits had been traced inland in 1835 was to a place 70 miles from the sea, on the southern shores of Lake Maeler, but they have since been traced by Erdmann to Linde, at the head of a lake of that name, to a distance of 130 miles west of Stockholm, and to a height of about 230 feet above the sea. Hence it appears, from the distinct assemblage of fossil shells found on the eastern and western coasts of Sweden, that the Baltic has been for a long period separated as now from the ocean, although the intervening tract of land was once much narrower, even after both seas had become inhabited by all the existing species of testacea.

Whether any of the land in Norway is now rising, must be determined by future investigations. Marine fossil shells, of recent species, have been collected from inland places near Drontheim; but Mr. Everest, in his 'Travels through Norway,' informs us that the small island of Munkholm, which is an insulated rock in the harbour of Drontheim, affords conclusive evidence of the land having in that region remained stationary for the last 8 centuries. The area of this isle does not exceed that of a small village; and by an official survey, its highest point has been determined to be 23 feet above the mean high-water mark, that is, the mean between neap and spring tides. Now, a monastery was founded there by Canute the Great, A.D. 1028, and 33 years before that time it was in use as a common place of execution.

According to the assumed average rate of rise in Sweden (about 40 inches in a century), we should be obliged to suppose that this island had been 3 feet 8 inches below high-water mark when it was originally chosen as the site of the monastery.

Professor Keilhau, of Christiania, after collecting the observations of his predecessors respecting former changes of level in Norway, and combining them with his own, has made the fact of a general change of level at some unknown but, geologically speaking, modern period (that is to say, within the period of the actual testaceous fauna), very evident. He infers that the whole country from Cape Lindesnæs to the North Cape, and beyond that as far as the fortress of Vardhuus, has been gradually upraised, and on the south-east coast the elevation has amounted to more than 600 feet. The marks which denote the ancient coast-lines are so nearly horizontal, that the deviation from horizontality, although the measurements have been made at a great number of points, is too small to be appreciated.

More recently (1844), however, it appears from the researches of M. Bravais, member of the French Scientific Commission of the North, that in the Gulf of Alten in Finmark, the most northerly part of Norway lying to the north of Lapland, there are two distinct lines of upraised ancient sea-coast, one above the other, which are not parallel, and both of them imply that within a distance of 50 miles a considerable slope can be detected in such a direction as to show that the ancient shores have undergone a greater amount of upheaval in proportion as we advance inland.*

The different heights at which horizontal raised beaches containing recent shells have been observed along the western and northern coasts of Norway, have been supposed to prove the suddenness of the upheaval of the land at successive periods; but when truly interpreted, these appearances prove rather that the elevatory force has been intermittent in its action, and that there have been long pauses in the process

* Quarterly Journ. of Geol. Soc. No. 4, p. 534. M. Bravais' observations were verified in 1849 by Mr. R. Chambers in his 'Tracings of N. of Europe,' p. 208.

of upheaval. They mark eras at which the level of the sea has remained stationary for ages, and during which new strata were deposited near or on the shore in some places, while in others the waves and currents had time to hollow out rocks, undermine cliffs, and throw up long ranges of shingle. They undoubtedly show that the movement has not been always uniform or continuous, but they do not establish the fact of any sudden alterations of level.

Subsidence of part of Greenland.—The rise of Scandinavia has naturally been regarded as a very singular and scarcely credible phenomenon, because no region on the globe has been more free within the times of authentic history from violent earthquakes. In common, indeed, with our own island, and with almost every spot on the globe, movements have been, at different periods, experienced, both in Norway and Sweden. But some of these, as for example during the Lisbon earthquake in 1755, may have been mere vibrations or undulatory movements of the earth's crust prolonged from a great distance. Others, however, have been sufficiently local to indicate a source of disturbance immediately under the country itself. Notwithstanding these shocks, Scandinavia has, upon the whole, been as tranquil in modern times, and as free from subterranean convulsions, as any region of equal extent on the globe. The same may be said of another large area in Greenland, which in modern times has been undergoing a slow and insensible movement, but in an opposite direction. Two Danish investigators, Dr. Pingel and Captain Graah, have brought to light abundant evidence of the sinking down of part of the west coast of Greenland, for a space of more than 600 miles from north to south. The observations of Captain Graah were made during a survey of Greenland in 1823–24, and afterwards in 1828–29; those by Dr. Pingel were made in 1830-32. It appears from various signs and traditions, that the coast has been subsiding for the last 4 centuries from the firth called Igaliko, in lat. 60° 43′ N., to Disco Bay, extending to nearly the 69th degree of north latitude. Ancient buildings on low rocky islands and on the shore of the mainland have been gradually submerged, and experience

has taught the aboriginal Greenlander never to build his hut near the water's edge. In one place the Moravian settlers have been obliged more than once to move inland the poles upon which their large boats were set, and the old poles still remain beneath the water as silent witnesses of the change.*

The fact of the gradual elevation and depression of land throughout vast areas of Europe and Arctic America, which we have considered in this chapter, partly in the historical period and partly in geological times immediately antecedent, leads us naturally to speculate on the wonderful changes which must be continually in progress in the subterranean foundations of these same countries. Whether we ascribe these changes to the expansion of solid matter exposed to hydrothermal action, or to the melting of rock, or the solidification of mineral masses, in whatever conjectures we indulge, we cannot doubt that at some unknown depths the structure of the crust of our globe is gradually undergoing very important modifications.

* See Proceedings of Geol. Soc. No. 42, p. 208. I also conversed with Dr. Pingel on the subject at Copenhagen in 1834.

CHAPTER XXXII.

CAUSES OF EARTHQUAKES AND VOLCANOS.

INTIMATE CONNECTION BETWEEN THE CAUSES OF VOLCANOS AND EARTHQUAKES—SUPPOSED ORIGINAL STATE OF FUSION OF THE PLANET—ITS SIMULTANEOUS AND UNIVERSAL FLUIDITY NOT PROVED BY ITS SPHEROIDAL FIGURE—ATTEMPT TO CALCULATE THE THICKNESS OF THE SOLID CRUST OF THE EARTH BY PRECESSIONAL MOTION—HEAT OF EARTH'S CRUST INCREASING WITH THE DEPTH, BUT NOT EQUALLY—NO INTERNAL TIDES OF SUPPOSED CENTRAL FLUID PERCEPTIBLE—SUPPOSED CHANGE OF AXIS OF EARTH'S CRUST—PARTIAL FLUIDITY OF THE EARTH'S CRUST MOST CONSISTENT WITH VOLCANIC PHENOMENA OF THE PAST AND PRESENT—ABANDONMENT OF THE DATA BY WHICH THE EARLIER GEOLOGISTS SUPPORTED THEIR THEORY OF THE PRISTINE FLUIDITY OF THE EARTH'S CRUST—DOCTRINE OF A CONTINUAL DIMINUTION OF TERRESTRIAL AND SOLAR HEAT CONSIDERED.

It will hardly be questioned, after the description before given of the phenomena of earthquakes and volcanos, that both of these agents have, to a certain extent, a common origin; and I may now, therefore, proceed to enquire into their probable causes. But, first, it may be well to recapitulate some of those points of relation and analogy which lead naturally to the conclusion that they spring from a common source.

The regions convulsed by violent earthquakes include within them the sites of all the active volcanos. Earthquakes, sometimes local, sometimes extending over vast areas, often precede volcanic eruptions. The subterranean movement and the eruption return again and again, at irregular intervals of time, and with unequal degrees of force, to the same spots. The action of either may continue for a few hours, or for several consecutive years. Paroxysmal convulsions are usually followed, in both cases, by long periods of tranquillity. Thermal and mineral springs are abundant in countries of earthquakes and active volcanos. Lastly, springs situated in districts considerably distant

from volcanic vents have been observed to have their temperature suddenly raised or lowered, and the volume of their water increased or lessened, by subterranean movements.

All these appearances are evidently more or less connected with the passage of heat from the interior of the earth to the surface; and where there are active volcanos, there must exist, at some unknown depth below, enormous masses of matter intensely heated, and, in many instances, in a constant state of fusion. We have first, then, to enquire, whence is this heat derived?

Supposed central fluidity of the earth.—It has long been a favourite conjecture that the whole of our planet was originally in a state of igneous fusion, and that the central parts still retain a great portion of their primitive heat. Some have imagined, with the late Sir William Herschel, that the elementary matter of the earth may have been first in a gaseous state, resembling those nebulæ which we behold in the heavens, and which are of dimensions so vast that some of them would fill the orbits of the remotest planets of our system. The increased power of the telescope has of late years resolved the greater number of these nebulous appearances into clusters of stars; but so long as they were confidently supposed to consist of aëriform matter, it was a favourite conjecture that they might, if concentrated, form solid spheres; and it was also imagined that the evolution of heat, attendant on condensation, might retain the materials of the new globes in a state of igneous fusion.

Without dwelling on such speculations, which can only have a distant bearing on geology, we may consider how far the spheroidal form of the earth affords sufficient ground for presuming that its primitive condition was one of universal fluidity. The discussion of this question would be superfluous, were the doctrine of original fluidity less popular; for it may well be asked, why the globe should be supposed to have had a pristine shape different from the present one?—why the terrestrial materials, when first called into existence, or assembled together in one place, should not have been subject to rotation, so as to assume at once that form

which alone could retain their several parts in a state of equilibrium?

Let us, however, concede that the statical figure may be a modification of some other pre-existing form, and suppose the globe to have been at first a perfect and quiescent sphere, covered with a uniform ocean—what would happen when it was made to turn round on its axis with its present velocity? This problem has been considered by Playfair in his Illustrations; and he has decided, that if the surface of the earth, as laid down in Hutton's theory, has been repeatedly changed by the transportation of the detritus of the land to the bottom of the sea, the figure of the planet must in that case, whatever it may have been originally, be brought at length to coincide with the spheroid of equilibrium.* The late Sir John F. W. Herschel also, in reference to the same hypothesis, observes, 'A centrifugal force would in that case be generated, whose general tendency would be to urge the water at every point of the surface to *recede* from the *axis*. A rotation might indeed be conceived so swift as to flirt the whole ocean from the surface, like water from a mop. But this would require a far greater velocity than what we now speak of. In the case supposed, the *weight* of the water would still keep it *on* the earth; and the tendency to recede from the axis *could* only be satisfied therefore by the water leaving the poles, and flowing towards the equator; there heaping itself up in a ridge, and being retained in opposition to its weight or natural tendency towards the centre by the pressure thus caused. This, however, could not take place without laying dry the polar regions, so that protuberant land would appear at the poles, and a zone of ocean be disposed around the equator. This would be the first or immediate effect. Let us now see what would afterwards happen if things were allowed to take their natural course.'

'The sea is constantly beating on the land, grinding it down, and scattering its worn-off particles and fragments, in the state of sand and pebbles, over its bed. Geological facts afford abundant proofs that the existing continents have

* Illust. of Hutt. Theory, § 435-443.

all of them undergone this process even more than once, and been entirely torn in fragments, or reduced to powder, and submerged and reconstructed. Land, in this view of the subject, loses its attribute of fixity. As a mass, it might hold together in opposition to forces which the water freely obeys; but in its state of successive or simultaneous degradation, when disseminated through the water, in the state of sand or mud, it is subject to all the impulses of that fluid. In the lapse of time, then, the protuberant land would be destroyed, and spread over the bottom of the ocean, filling up the lower parts, and tending continually to remodel the surface of the solid nucleus, in correspondence with the *form of equilibrium.* Thus, after a sufficient lapse of time, in the case of an earth in rotation, the polar protuberances would gradually be cut down and disappear, being transferred to the equator (as being *then* the *deepest sea*), till the earth would assume by degrees the form we observe it to have—that of a flattened or *oblate* ellipsoid.'

'We are far from meaning here to trace the process *by which* the earth really assumed its actual form; all we intend is to show that this is the form to which, under a condition of a rotation on its axis, it must *tend*, and which it would attain even if originally and (so to speak) perversely constituted otherwise.'*

Although in the above passage no mention is made of subaërial denudation, yet it must be understood that it would play a leading part in the degradation of the polar land under the condition above assumed. Sir John Herschel has also confined his observations to the effects of aqueous causes only; neither he nor Playfair seems to have followed out the same enquiry with reference to another part of Hutton's system; namely, that which assumes the successive fusion by heat of different parts of the solid earth. Yet the progress of geology has continually strengthened the evidence in favour of the doctrine that local variations of temperature have melted one part after another of the earth's crust, and this influence has perhaps extended downwards to the very centre. If,

* Herschel's Astronomy, chap. iii.; also 7th edition, chap. iv. p. 142.

therefore, before the globe had assumed its present form, it was made to revolve on its axis, all matter to which freedom of motion was given by fusion, must before consolidating have been impelled towards the equatorial regions in obedience to the centrifugal force. Thus, lava flowing out in superficial streams would have its motion retarded when its direction was towards the pole, accelerated when towards the equator; or if lakes and seas of lava existed beneath the earth's crust in equatorial regions, as probably now beneath the Peruvian Andes, the imprisoned fluid would force outwards and permanently upheave the overlying rocks. The statical figure, therefore, of the terrestrial spheroid (of which the longer diameter exceeds the shorter, by about twenty-five miles), may have been the result of gradual and even of existing causes, and not of a primitive, universal, and simultaneous fluidity.*

Experiments made with the pendulum, and observations on the manner in which the earth attracts the moon, have shown that our planet is not an empty sphere, but, on the contrary, that its interior, whether solid or fluid, has a higher specific gravity than the exterior. It has also been inferred from certain inequalities in the moon's motion, that there is a regular increase in density from the surface towards the centre, and that the equatorial protuberance is continued inwards; that is to say, that layers of equal density are arranged elliptically, and symmetrically, from the exterior to the centre.

The mean density of the earth has been computed by Laplace to be about $5\frac{1}{2}$, or more than 5 times that of water. Now the specific gravity of many of our rocks is from $2\frac{1}{2}$ to 3, and the greater part of the metals range between that density and 21. Hence some have imagined that the terrestrial nucleus may be metallic—that it may correspond, for example, with the specific gravity of iron, which is about 7. But here a curious question arises in regard to the form which materials, whether fluid or solid, might assume, if subjected to the enormous pressure which must obtain at the

* See Hennessy, On Changes in Earth's Figure, &c. Journ. Geol. Soc. Dublin, 1849; and Proc. Roy. Irish Acad. vol. iv. p. 337.

earth's centre. Water, if it continued to decrease in volume according to the rate of compressibility deduced from experiment, would have its density doubled at the depth of 93 miles, and be as heavy as mercury at the depth of 362 miles. Dr. Young computed that, at the earth's centre, steel would be compressed into one-fourth, and stone into one-eighth of its bulk.* It is more than probable, however, that after a certain degree of condensation, the compressibility of bodies may be governed by laws altogether different from those which we can put to the test of experiment; but the limit is still undetermined, and the subject is involved in such obscurity, that we cannot wonder at the variety of notions which have been entertained respecting the nature and conditions of the central nucleus. Some have conceived it to be fluid, others solid; some have imagined it to have a cavernous structure, and have even endeavoured to confirm this opinion by appealing to observed irregularities in the vibrations of the pendulum in certain countries.

An attempt has been made by Mr. Hopkins to determine the least thickness which can be assigned to the solid crust of the globe, if we assume the whole to have been once perfectly fluid, and a certain portion of the exterior to have acquired solidity by gradual refrigeration. This result he has endeavoured to obtain by a new solution of the delicate problem of the precessional motion of the pole of the earth, caused, as before mentioned, p. 275, Vol. I., by the attraction of the sun and moon, and principally the moon, on the protuberant parts at the earth's equator; for if these parts were solid to a great depth, the motion thus produced would differ considerably from that which would exist if they were perfectly fluid, and incrusted over with a thin shell only a few miles thick. In other words, the disturbing action of the moon will not be the same upon a globe all solid and upon one nearly all fluid, nor will it be the same upon a globe in which the solid shell forms one-half of the mass, and another in which it forms only one-tenth.

Mr. Hopkins has, therefore, calculated the amount of

* Young's Lectures, and Mrs. Somerville's Connection of the Physical Sciences, p. 90.

precessional motion which would result if we assume the earth to be constituted as above stated; *i.e.* fluid internally, and enveloped by a solid shell; and he finds that the amount will not agree with the observed motion, unless the crust of the earth be of a certain thickness. In calculating the exact amount, some ambiguity arises in consequence of our ignorance of the effect of pressure in promoting the solidification of matter at high temperatures. The hypothesis least favourable for a great thickness is found to be that which assumes the pressure to produce no effect on the process of solidification. Even on this extreme assumption, the thickness of the solid crust must be nearly *four hundred miles*, and this would lead to the remarkable result that the proportion of the solid to the fluid part would be as 49 to 51, or, to speak in round numbers, there would be nearly as much solid as fluid matter in the globe. The conclusion, however, which Mr. Hopkins announces as that to which his researches have finally conducted him, is thus expressed: 'Upon the whole, then, we may venture to assert that the minimum thickness of the crust of the globe, which can be deemed consistent with the observed amount of precession, cannot be less than one-fourth or one-fifth of the earth's radius;' that is, from 800 to 1,000 miles.*

It will be remarked, that this is a *minimum*, and any still *greater* amount would be quite consistent with the actual phenomena; the calculations not being opposed to the supposition of the general solidity of the entire globe. Nor do they preclude us from imagining that great lakes and seas of melted matter may be distributed through a shell 400 or 800 miles thick, provided they be so inclosed as to move with it, whatever motion of rotation may be communicated by the attraction of the sun and moon. M. Delaunay, the eminent French astronomer, in his paper on the 'Hypothesis of the Internal Fluidity of the Terrestrial Globe,'† has brought forward some objections to the arguments advanced by Mr.

* Phil. Trans. 1839, and Researches in Physical Geology, 1st, 2nd, and 3rd series, London, 1839—1842; also on Phenomena and Theory of Volcanos, Report Brit. Assoc. 1847.

† Comptes Rendus for July 13, 1868.

Hopkins; but Sir William Thomson, after carefully considering these objections, states that the hypothesis of a viscous fluid assumed by M. Delaunay can be mathematically proved to be insufficient for the phenomena, which cannot, he believes, be accounted for unless the crust have a thickness of at least 2,000 or 2,500 miles, and a rigidity approaching that of a globe of solid glass. *

Rate of heat increasing with depth.—The hypothesis of internal fluidity calls for the more attentive consideration, as it has been found that the heat in mines augments in proportion as we descend. Observations have been made, not only on the temperature of the air in mines, but on that of the rocks, and on the water issuing from them. The mean rate of increase, calculated from the most careful experiments yet made in 2 shafts, one near Durham, and another near Manchester, each of them 2,000 feet deep, is 1° Fahrenheit for every increase of depth of from 65 to 70 feet, a rate of increase considerably less than that previously deduced from coal-mines in the same districts.† This rate, however, agrees very nearly with previous observations made in several of the principal lead and silver mines in Saxony, which gave 1° Fahr. for every 65 feet. In this case, the bulb of the thermometer was introduced into cavities purposely cut in the solid rock at depths varying from 200 to about 900 feet. But in other mines of the same country, it was necessary to descend thrice as far for each degree of temperature.‡

A thermometer was fixed in the rock of the Dolcoath mine, in Cornwall, by Mr. Fox, at the great depth of 1,380 feet, and frequently observed during 18 months; the mean temperature was 68° Fahr., that of the surface being 50°, which gives 1° for every 75 feet.

Kupffer, after an extensive comparison of the results in different countries, makes the increase 1° Fahr. for about every 37 English feet.§ M. Cordier announces, as the result

* Nature, Vol. V., January 18, 1872, p. 223, and Feb. 1st, p. 257.

† These observations were made by Professor Philips.

‡ Cordier, Mém. de l'Instit. tom. vii.

§ Pog. Ann. tom. xv. p. 159.

of his experiments and observations on the temperature of the interior of the earth, that the heat increases rapidly with the depth; but the increase does not follow the same law over the whole earth, being twice or three times as much in one country as in another, and these differences are not in constant relation either with the latitudes or longitudes of places. He is of opinion, however, that the increase would not be overstated at 1° Cent. for every 25 mètres, or about 1° Fahr. for every 45 feet.* The experimental well bored at Grenelle, near Paris, gave, as before stated (Vol. I. p. 387), an increase of about 1° Fahr. for every 60 English feet to the depth of 1,800 feet.

At Naples, according to Mr. Mallet, the water in the Artesian well at the Royal Palace, at the depth of 1,460 feet, has a temperature of only 68° Fahr., which, deducting for the mean temperature of the surface soil, 61° Fahr., gives an increment of only 1° Fahr. for every 208 feet in depth. Another well in the same city, only a mile distant from the former and 909 feet deep, gives 1° Fahr. for 83 feet in depth. It is conjectured that the low temperature of the well first mentioned may be due to the cooling influence both of fresh and sea water which may be filtered through porous beds of tufa.

Some writers have endeavoured to refer these phenomena (which, however discordant as to the ratio of increasing heat, appear all to point one way) to the condensation of air constantly descending from the surface into the mines. For the air under pressure would give out latent heat, on the same principle as it becomes colder when rarefied in the higher regions of the atmosphere. But the argument has been answered in a satisfactory manner by Mr. Fox, who has shown, from observations made in the mines of Cornwall, that the difference of temperature between the descending and ascending currents varies from 9° to 17° Fahr., and therefore that the accession of heat is greater than could be supposed to be caused by the condensation of the air.†

* See M. Cordier's Memoir on the Temperature of the Interior of the Earth, June, 1827. Mém. de l'Instit. tom. vii., and Edin. New. Phil. Journal, No. viii. p. 273.

† Phil. Mag. and Ann. Feb. 1830.

If we adopt the mean increase of 1° Fahr. for every 65 feet of depth, and assume, with the advocates of central fluidity, that the increasing temperature is continued downwards for an indefinite distance, we should reach the ordinary boiling point of water at rather more than 2 miles below the surface, and at the depth of about 34 miles should arrive at the melting point of iron, or 2,786° Fahr. according to Daniell's pyrometer, a heat sufficient to fuse almost every known substance. In the diagram, fig. 134, p. 212, the outer circular line represents a thickness of 25 miles, and the space between the 2 circles, together with the lines themselves, represents a crust of 200 miles in depth. If, therefore, the heat went on increasing at the rate above alluded to, we should encounter not far below the outer line a temperature many times greater than that sufficient to melt the most refractory substances known to us. At much greater depths, and long before approaching the central nucleus, the heat would be so intense (160 times that of melted iron), that we cannot conceive the external crust to resist fusion.*

It may be said that we may stand upon the hardened surface of a lava current while it is still in motion—nay, may descend into the crater of Vesuvius after an eruption, and stand on the scoriæ while every crevice shows that the rock is red-hot 2 or 3 feet below us; and at a somewhat greater depth, all is, perhaps, in a state of fusion. May not, then, a much more intense heat be expected at the depth of several hundred yards or miles? The answer is—that until a great quantity of heat has been given off, either by the emission of lava, or in a latent form by the evolution of steam and gas, the melted matter continues to boil in the crater of a volcano. But ebullition ceases when there is no longer a sufficient supply of heat from below, and then a crust of lava may form on the top, and showers of scoriæ

* The expansion of platinum was the test employed by Mr. Daniell in his pyrometer, which was found to yield uniform and constant results, in harmony with those derived from other independent sources. But Dr. Percy informs me that neither this nor any other test yet invented for measuring intense heat can be fully depended upon. Malleable iron, he remarks, requires more heat for its fusion than wrought iron, in which the metal is mixed with a small percentage of carbon.

may then descend upon the surface, and remain unmelted. If the internal heat be raised again, ebullition will recommence, and soon fuse the superficial crust. So in the case of the moving current, we may safely assume that no part of the liquid beneath the hardened surface is much above the temperature sufficient to retain it in a state of fluidity.

M. Poisson, in his Mathematical Theory of Heat, published in 1835, controverted the doctrine of the high temperature of a central nucleus, and declared his opinion that if the globe had ever passed from a liquid to a solid state in consequence of the loss of heat by radiation, the cooling and consolidation of the nucleus would have begun at the earth's centre.

Many of the advocates of central fluidity have admitted that there must be tides in the internal ocean; but their effect, says Cordier, has become feeble, although originally, when the fluidity of the globe was perfect, 'the rise and fall of these ancient land tides could not have been less than from 13 to 16 feet.' Now, granting for a moment that these tides have become so feeble as to be incapable of causing the fissured shell of the earth to be first uplifted and then depressed every 6 hours, still may we not ask whether, in every volcano during an eruption, the lava, which is supposed to communicate with a great central ocean, would not rise and fall sensibly, or whether, in a crater like Stromboli, where there is always melted matter in a state of ebullition, the ebbing and flowing of the liquid would not be constant?

Supposed change of axis of earth's crust.—An ingenious paper was read before the Royal Society,* by Mr. Evans, in 1866, in which he suggested that former changes of climate on the surface might be connected with the sliding of a solid shell over an internal fluid nucleus. Granting for the moment the fluidity (in spite of the arguments I have adduced against it, p. 204), the equilibrium of the external shell might, no doubt, be disturbed by the transfer of the sediment from one part of the surface to another, or by the upheaval of new continents and islands; and Mr. Evans shows that, whenever matter is abstracted from one part and added to another, the centrifugal force of the augmented extraneous matter would

* J. Evans, Royal Society Proceedings, 1866.

tend to draw over the shell towards the equator, or an opposite effect would be produced if the surface was relieved of part of its weight, in which case the lighter part would move towards the pole.

Newton, and afterwards Laplace, had argued against the probability of a shifting of the earth's axis of rotation, and more recently Mr. Airy had among other arguments pointed out that the elevation of mountain chains at certain geological periods, which had been proposed as causing an alteration in the earth's centre of gravity, was an insignificant cause, since the size of such mountain masses was very minute, when compared to the equatorial protuberance, which he says is a mass of matter 25,000 miles long, 6,000 miles broad, and 13 miles deep. But Mr. Evans suggests that the axis of rotation of the nucleus might remain unchanged, while a solid shell not more, perhaps, than 25 miles in thickness might have its axis of rotation altered. To this hypothesis there are several objections:—

First, in all geological times, the transfer of sediment has been taking place not only from higher to lower latitudes, but also from lower to higher. There is the like tendency in the various elevations and depressions of land simultaneously in progress to balance each other. It is only the excess of alteration in one direction that can be available as a disturbing cause, and we can hardly imagine this excess to be important enough to cause a sensible change in the axis of rotation even of the external shell, such as might explain the altered climate of the same country in successive geological periods.

Secondly, a greater difficulty arises out of the fact that the earth is a spheroid and not a perfect sphere, since it becomes necessary to imagine the fluidity of the nucleus to be so perfect as to allow the shell to slide freely over it. If the lower or inner surface of the envelope be irregular in shape, or if it be even viscous in part, great resistance would be offered to any change in its position. Its freedom of motion would be checked by its not fitting the nucleus, let its change of position be ever so slight, and this change

could only be effected by the most violent friction, attended by the bending and rending of the incumbent mass.

Partial fluidity of the earth's crust most consistent with volcanic phenomena.—It must not be forgotten that the geological speculations still in vogue respecting the original fluidity of the planet, and the gradual consolidation of its external shell, belong to a period when theoretical ideas were entertained as to the relative age of the crystalline foundations of that shell wholly at variance with the present state of our knowledge. It was formerly imagined that all granite was of very high antiquity, and that rocks such as gneiss, mica-schist, and clay slate, were also anterior in date to the existence of organic beings on a habitable surface. It was, moreover, supposed that these primitive formations, as they were called, implied a continual thickening of the crust at the expense of the original fluid nucleus. These notions have been universally abandoned. It is now ascertained that the granites of different regions are by no means all of the same antiquity, and that it is hardly possible to prove any one of them to be as old as the oldest known fossil organic remains. It is likewise now admitted, that gneiss and other stratified crystalline strata are sedimentary deposits which have undergone metamorphic action, and they can almost all be demonstrated to be newer than the lately discovered fossil called Eozoon Canadense. It follows from such views, which are of comparatively modern date, that instead of these crystalline rocks, which are often of enormous volume, implying a constant thickening of the earth's crust from the remotest periods, they most of them bear testimony to aqueous denudation on a vast scale, or, in other words, they bespeak the removal of just as much solid matter from one part of the earth's circumference as has been contemporaneously accumulated in the shape of new strata in some other part. It was, moreover, taken for granted by the earlier theorists, without any sufficient geological proof, that the energy of the volcanic force was far more intense in the remoter periods of the earth's history than in the later. No adequate conception had been formed of the great lapse of time occupied in the elaboration of each of the principal groups of

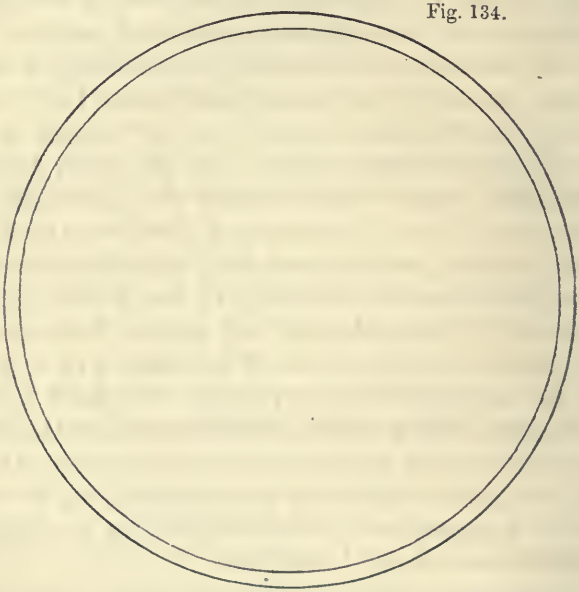
the primary, secondary, and tertiary fossiliferous rocks, and of the gradual manner in which contemporaneous volcanic products were locally developed during each of those periods.

The limited areas to which the volcanic outbursts were confined at any one epoch, the Cretaceous for example, are proved by the general absence in strata of the same age of associated igneous formations. It can be demonstrated that the volcanic power was by no means dormant, but it was locally developed. There are wide tracts in North America and Russia where very ancient strata, such as the Silurian and Carboniferous, are horizontal and undisturbed, and wholly devoid of contemporaneous igneous products, showing that such areas were not only free from volcanic action in Palæozoic times, but that they have never been the theatres of such action at any subsequent epoch. On the other hand, we often find that regions where showers of volcanic ashes and the intrusion of igneous matter into fissures were once most frequent, are now entirely free from volcanic disturbance. The continual transfer, therefore, of the points of chief development of the earthquake and volcano from one part of the earth's crust to another, is established as a general law by the clearest geological evidence. We have also seen (Chapter XXIII.) that volcanic operations are now in progress on the grandest scale, and also that single currents of lava of modern date are as voluminous as any which can be shown to have ever poured out in the earliest eras to which our geological retrospect can be carried.

The doctrine, therefore, of the pristine fluidity of the interior of the earth, and of the gradual solidification of its crust consequent on the loss of internal heat by radiation into space, is one of many scientific hypotheses, which has been adhered to after the props by which it was at first supported have given way one after another. The astronomer may find good reasons for ascribing the earth's form to the original fluidity of the mass in times long antecedent to the first introduction of living beings into the planet; but the geologist must be content to regard the earliest monuments which it is his task to interpret as belonging to a period when the crust had already acquired great solidity and thickness, probably as great as

it now possesses, and when volcanic rocks not essentially differing from those now produced were formed from time to time, the intensity of volcanic heat being neither greater nor less than it is now. This heat has, no doubt, given rise at successive periods to many of the leading changes in the form and structure of the earth's crust; but their magnitude is by no means such as to warrant our invoking the igneous fusion of the whole planet to account for them. If the reader will refer to the accompanying diagram, fig. 134, he may

Fig. 134.



Section of the earth in which the breadth of the outer boundary line represents a thickness of 25 miles; the space between the circles, including the breadth of the lines, 200 miles.

convince himself that a machinery more utterly disproportionate to the effects which it is required to explain was never appealed to. The outer circular line of the diagram represents a portion of the earth's diameter equal to 25 miles; so that if the loftiest mountain chains, even such as the Himalaya, 5 miles in their greatest height, could be expressed by white marks within this line, they would form a feature in it which would be scarcely appreciable.

The space between the two circles, including the thickness of the lines themselves, has a breadth or diameter of 200 miles. Let us, then, suppose very thin lines 2 inches long, and equal in width to only $\frac{1}{5}$ of the outer line, to be drawn here and there within this crust of 200 miles in thickness. These lines, faint and unimportant as they would appear, might nevertheless represent sections of seas or oceans of melted lava 5 miles deep and 5,000 miles long. It cannot be denied that the expansion, melting, solidification and shrinking of such subterranean seas of lava at various depths, might suffice to cause great movements or earthquakes at the surface, and even great rents in the earth's crust several thousand miles long, such as may be implied by the lineally arranged cones of the Andes or mountain chains like the Alps.

Supposed secular loss of heat in the solar system.—It is a favourite dogma of some physicists, that not only the earth but the sun itself is continually losing a portion of its heat, and that as there is no known source by which it can be restored, we can foresee the time when all life will cease to exist upon this planet, and on the other hand we can look back to the period when the heat was so intense as to be incompatible with the existence of any organic beings such as are known to us in the living or fossil world.

I shall consider in the next chapter the connection of solar and terrestrial magnetism, and the extent to which electricity may be conceived to be a source of volcanic heat. But when we consider the discoveries recently made of the convertibility of one kind of force into another, and how light, heat, magnetism, electricity, and chemical affinity are intimately connected, we may well hesitate before we accept the theory of the constant diminution from age to age of a great source of dynamical and vital power. 'All reflecting minds are now convinced,' says Mr. Grove, 'that force cannot be annihilated. If light, then, is lost as light (and the observations of Struvé seem to show this to be so—that, in fact, a star may be so far distant that it can never be seen in consequence of its luminous emissions becoming extinct), what becomes of the transmitted force lost as light, but ex-

isting in some other form? So with heat; our sun, our earth, and planets are constantly radiating heat into space, so, in all probability, are the other suns, the stars, and their attendant planets. What becomes of the heat thus radiated into space? If the universe have no limit, and it is difficult to conceive one, there is a constant evolution of heat and light; and yet more is given off than is received by each (self-luminous) cosmical body, for otherwise night would be as light and as warm as day. What becomes of the enormous force thus apparently non-recurrent in the same form? Does it return as palpable motion? Does it move or contribute to move suns and planets? and can it be conceived as a force similar to that which Newton speculated on as universally repulsive and capable of being substituted for universal attraction?'* A geologist, in search of some renovating power, by which the amount of heat may be made to continue unimpaired for millions of years, past and future, in the solid parts of the earth, although perpetually shifting the chief points of its development, has been compared to one who dreams he can discover a source of perpetual motion, and invent a clock with a self-winding apparatus. But why should we despair of detecting proofs of such a regenerating and self-sustaining power in the works of a Divine Artificer? What is the origin of the force which governs the motions of the heavenly bodies? It has been likened to the intellectual power of the human will, which initiates and directs all our muscular actions. To define its nature, has hitherto baffled the efforts of the metaphysician and natural philosopher, but assuredly we are not yet so far advanced in our knowledge of the system of the universe as to be entitled to declare that a great dynamical force like that of heat is on the wane.

* British Assoc. Address, Nottingham, August 22, 1866.

CHAPTER XXXIII.

CAUSES OF EARTHQUAKES AND VOLCANOS—*continued.*

AGENCY OF STEAM IN VOLCANIC ERUPTIONS—GEYSERS OF ICELAND—NEW ZEALAND GEYSERS—EXPANSIVE POWER OF LIQUID GASES—ACCESS OF SALT WATER, ATMOSPHERIC AIR, AND FRESH WATER TO THE VOLCANIC FOCI—HOW THE SUCCESSIVE DEVELOPMENT OF VOLCANIC HEAT IN THE EARTH'S CRUST CAUSES IT TO RESEMBLE A BODY COOLING FROM A GENERAL STATE OF FUSION—FLEXIBILITY OF THE EARTH'S CRUST—ELECTRICITY AND MAGNETISM CONSIDERED AS SOURCES OF VOLCANIC HEAT—CHEMICAL ACTION—CAUSES OF PERMANENT ELEVATION AND SUBSIDENCE OF LAND—BALANCE OF DRY LAND, HOW PRESERVED—RECAPITULATION OF CHAPTERS XXXII. AND XXXIII.

Agency of steam in volcanic eruptions.—We have seen that almost all the active volcanos are on sea-coasts or in islands. 'Out of 225 volcanos,' says Sir John Herschel, 'which are known to have been in eruption within the last 150 years, there is only a single instance of one more than 320 miles from the sea, and even that one, Mount Demawend in Persia, is on the edge of the Caspian, the largest of all the inland seas.' Jorullo in Mexico, which was in eruption in 1759, is no less than 120 miles from the nearest ocean; but, as Dr. Daubeny observes, it forms part of a train of volcanos one extremity of which is near the sea. (See Vol. I. p. 585, and Chap. XXVII. Vol. II. p. 53.) The volcano said to have been in activity in the 7th century in Central Tartary is 260 geographical miles from the ocean, but near a large lake. (Vol. I. p. 592.)

Mr. Dana, in his valuable and original observations on the volcanos of the Sandwich Islands, reminds us of the prodigious volume of atmospheric water which must be absorbed into the interior of such large and lofty domes, composed as they are entirely of porous lava. To this source alone he refers the production of the steam by which the melted matter

is propelled upwards, even to the summit of cones 3 miles in height.*

Geysers of Iceland.—The extent to which porous rocks are percolated by rain-water to great depths in almost every region, however far from the sea, has been alluded to in our chapter on Springs (Vol. I. p. 384); and as there is no doubt that ordinary steam plays a prominent part in volcanic eruptions generally, it may be well before going farther to consider attentively a case in which we know it to be exclusively the moving power, namely, that of the Geysers of Iceland. These intermittent hot springs occur in a district situated in the south-western division of Iceland, where nearly 100 of them are said to break out within a circle of 2 miles. That the water is of atmospheric origin, derived from rain and melted snow, is proved, says Professor Bunsen, by the nitrogen which rises from them either pure or mixed with other gases. The springs rise through a thick current of lava, which may perhaps have flowed from Mount Hecla, the summit of that volcano being seen from the spot at the distance of more than 30 miles. In this district the rushing of water is sometimes heard in chasms beneath the surface; for here, as on Etna, rivers flow in subterranean channels through the porous and cavernous lavas. It has more than once happened, after earthquakes, that some of the boiling fountains have increased or diminished in violence and volume, or entirely ceased, or that new ones have made their appearance—changes which may be explained by the opening of new rents and the closing of pre-existing fissures.

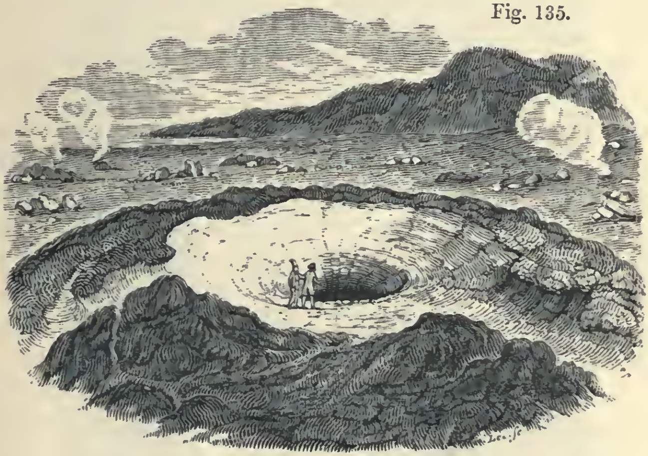
Few of the Geysers play longer than 5 or 6 minutes at a time, although sometimes half an hour. The intervals between their eruptions are for the most part very irregular. The Great Geyser rises out of a spacious basin at the summit of a circular mound composed of siliceous incrustations deposited from the spray of its waters. The diameter of this basin, in one direction, is 56 feet, and 46 in another. (See fig. 135.)

In the centre is a pipe 78 feet in vertical depth, and

* Geology of American Exploring Expedition, p. 369.

from 8 to 10 feet in diameter, but gradually widening as it rises into the basin. The inside of the basin is whitish, consisting of a siliceous crust, and perfectly smooth, as are likewise two small channels on the sides of the mound, down which the water escapes when the bowl is filled to the margin. The circular basin is sometimes empty, as represented in the following sketch; but is usually filled with beautifully transparent water in a state of ebullition. During the rise of the boiling water in the pipe, especially when the

Fig. 135.



View of the crater of the Great Geyser in Iceland.

ebullition is most violent, and when the water is thrown up in jets, subterranean noises are heard, like the distant firing of cannon, and the earth is slightly shaken. The sound then increases, and the motion becomes more violent, till at length a column of water is thrown up, with loud explosions, to the height of 100 or 200 feet. After playing for a time like an artificial fountain, and giving off great clouds of vapour, the pipe or tube is emptied; and a column of steam, rushing up with amazing force and a thundering noise, terminates the eruption.

If stones are thrown into the crater, they are instantly ejected; and such is the explosive force, that very hard rocks are sometimes shivered by it into small pieces. Henderson found that by throwing a great quantity of large stones into

the pipe of Strokkur, one of the Geysers, he could bring on an eruption in a few minutes.* The fragments of stone, as well as the boiling water, were thrown in that case to a much greater height than usual. After the water had been ejected, a column of steam continued to rush up with a deafening roar for nearly an hour; but the Geyser, as if exhausted by this effort, did not send up a fresh eruption when its usual

Fig. 136.

Eruption of the New Geyser in 1810. (Mackenzie.)

interval of rest had elapsed. The account given by Sir George Mackenzie of a Geyser which he saw in eruption in 1810 (see fig. 136), agrees perfectly with the above description by Henderson. The steam and water rose for half an hour to the height of 70 feet, and the white column remained vertical, notwithstanding a brisk gale of wind which was blowing against it. Stones thrown into the pipe were pro-

* Journal of a Residence in Iceland, p. 74.

jected to a greater height than the water. To leeward of the vapour, a heavy shower of rain was seen to fall.*

New Zealand Geysers.—The Geysers of New Zealand, although they have hitherto attracted less notice, are quite as numerous and remarkable as those of Iceland. They occur in thousands on the Northern Island, forming three parallel lines striking in the direction of N. 36° E. In a valley called Orakeikorako, on the river Waikato, Dr. Hochstetter counted 76 points of eruption in view at one time, many of them forming intermittent geyser-like fountains, with periodical water eruptions. The phenomena exhibited by these hot springs are throughout similar to those of Iceland, and the incrustations deposited by them are, in like manner, siliceous, and not calcareous. The intermittent springs, called by the natives Puias, which at certain periods give forth regular geyser-like water eruptions, form a class quite distinct from the Ngawhas, or permanent springs, the surface of which either remains in a state of repose, or in uniform ebullition; but both kinds owe their origin, says Dr. Hochstetter, to the water permeating the surface and sinking into the bowels of the earth, where it becomes heated by volcanic fires.†

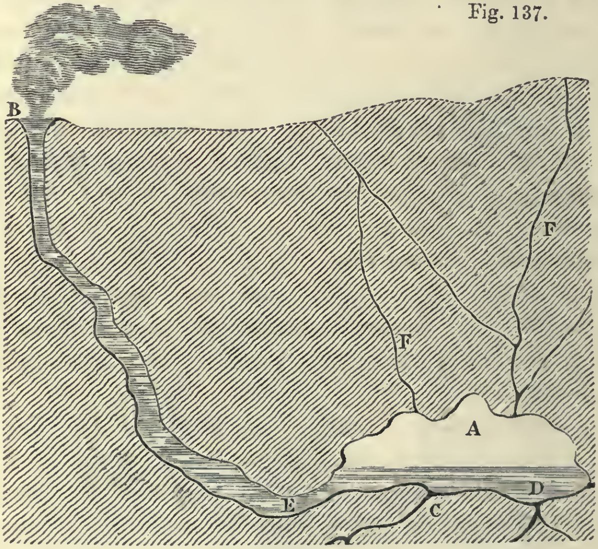
Causes of Geysers.—Among the different theories proposed to account for the phenomena of Geysers, I shall first mention one suggested by Sir J. Herschel. An imitation of these jets, he says, may be produced on a small scale, by heating red-hot the stem of a tobacco pipe, filling the bowl with water, and so inclining the pipe as to let the water run through the stem. Its escape, instead of taking place in a continued stream, is then performed by a succession of violent explosions, at first of steam alone, then of water mixed with steam; and, as the pipe cools, almost wholly of water. At every such paroxysmal escape of the water, a portion is driven back, accompanied with steam, into the bowl. The intervals between the explosions depend on the heat, length, and inclination of the pipe; their continuance, on its thickness and conducting

* Mackenzie's Iceland.

† Hochstetter, New Zealand, 1867, p. 432.

power.* The application of this experiment to the Geysers merely requires that a subterranean stream, flowing through the pores and crevices of lava, should suddenly reach a fissure, around which the rock is red-hot or nearly so. Steam would immediately be formed, which, rushing up the fissure, might force up water along with it to the surface, while, at the same time, part of the steam might drive back the water of the supply for a certain distance towards its source. And when, after the space of some minutes, the steam was all

Fig. 137.



Supposed reservoir and pipe of a Geyser in Iceland.†

condensed, the water would return, and a repetition of the phenomena take place.

There is, however, another mode of explaining the action of the Geyser, perhaps more probable than that above described. Suppose water percolating from the surface of the earth to penetrate into the subterranean cavity A D (fig. 137) by the fissures F F, while, at the same time, steam at an extremely high temperature, such as is commonly given out from the rents of lava currents during congelation, emanates from the fissures C. A portion of the steam is at first con-

* MS. read to Geol. Soc. of London, Feb. 29, 1832.

† From Sir George Mackenzie's Iceland.

densed into water, while the temperature of the water is raised by the latent heat thus evolved, till, at last, the lower part of the cavity is filled with boiling water and the upper with steam under high pressure. The expansive force of the steam becomes, at length, so great, that the water is forced up the fissure or pipe E B, and runs over the rim of the basin. When the pressure is thus diminished, the steam in the upper part of the cavity A expands, until all the water D is driven into the pipe; and when this happens, the steam, being the lighter of the two fluids, rushes up through the water with great velocity. If the pipe be choked up artificially, even for a few minutes, a great increase of heat must take place; for it is prevented from escaping in a latent form in steam; so that the water is made to boil more violently, and this brings on an eruption.

Professor Bunsen, before cited, adopts this theory to account for the play of the 'Little Geyser,' but says it will not explain the phenomena of the Great one. He considers this, like the others, to be a thermal spring, having a narrow funnel-shaped tube in the upper part of its course, where the walls of the channel have become coated over with siliceous incrustations. At the mouth of this tube the water has a temperature, corresponding to the pressure of the atmosphere, of about 212° Fahr., but at a certain depth below it is much hotter. This the Professor succeeded in proving by experiment; a thermometer suspended by a string in the pipe rising to 260° Fahr., or no less than 48° above the boiling point of ordinary atmospheric pressure. After the column of water has been expelled, what remains in the basin and pipe is found to be much cooled.*

Previously to these experiments of Bunsen and Descloizeaux, made in Iceland in 1846, it would scarcely have been supposed possible that the lower part of a free and open column of water could be raised so much in temperature without causing a circulation of ascending and descending currents, followed by an almost immediate equalisation of heat. Such circulation is no doubt impeded greatly by the sides of the well not being vertical, and by numerous contractions of its diameter,

* Bunsen. Poggendorf. Annalen der Physik, vol. lxxii.

but the phenomenon may be chiefly due to another cause. According to experiments on the cohesion of liquids by Mr. Donny of Ghent, it appears that when water is freed from all admixture of air, its temperature can be raised, even under ordinary atmospheric pressure, to 275° Fahr., so much does the cohesion of its molecules increase* when they are not separated by particles of air. As water long boiled becomes more and more deprived of air, it is probably very free from such intermixture at the bottom of the Geysers.

Among other results of the experiments of Bunsen and his companion, they convinced themselves that the column of fluid filling the tube is constantly receiving accessions of hot water from below, while it becomes cooler above by evaporation on the broad surface of the basin. They also came to a conclusion of no small interest, as bearing on the probable mechanism of ordinary volcanic eruptions, namely, that the tube itself is the main seat or focus of mechanical force. This was proved by letting down stones suspended by strings to various depths. Those which were sunk to considerable distances from the surface were not cast up again when the next eruption of the Geyser took place, whereas those nearer the mouth of the tube were ejected to a height of 100 feet. Other experiments also were made, tending to demonstrate the singular fact, that there is often scarcely any motion below, when a violent rush of steam and water is taking place above. It seems that when a lofty column of water possesses a temperature increasing with the depth, any slight ebullition or disturbance of equilibrium in the upper portion may first force up water into the basin, and then cause it to flow over the edge. A lower portion, thus suddenly relieved of part of its pressure, expands and is converted into vapour more rapidly than the first, owing to its greater heat. This allows the next subjacent stratum, which is much hotter, to rise and flash into a gaseous form, and this process goes on till the ebullition has descended from the middle to near the bottom of the funnel.†

* See Mr. Horner's Anniversary Address, Quart. Journ. Geol. Soc. 1847, liii.

† Liebig's Annalen der Chimie und Pharmacie, translated in 'Reports and Memoirs' of Cavendish Soc. London, 1848, p. 351.

Dr. Tyndall has produced a most perfect artificial representation of this process by heating from below a tube of galvanised iron filled with water, the mouth of the tube being made to pass upwards into a basin. As soon as the water becomes heated near enough to the boiling point it is ejected into the atmosphere, and this continues regularly at intervals of five minutes, the supply being kept up as in the real Geyser by the falling back of the cooled water into the tube. By stopping the mouth of the tube with a cork, and thus causing the heat to accumulate more rapidly, he was able to hasten the eruptions in the same manner as the Strokkur Geyser, in Iceland (see p. 218), is made to explode by stopping its mouth with clods of earth. This beautiful illustration of Bunsen's theory 'proves experimentally,' says Dr. Tyndall, 'that the Geyser tube itself is the sufficient cause of the eruptions, and we are relieved from the necessity of imagining underground caverns filled with water and steam, which were formerly regarded as necessary to the production of these wonderful phenomena.' *

Expansive power of liquid gases.—Although aqueous vapour or steam forms a principal part of the aëriform fluids which rush out for days, months, or even years continuously from volcanic vents, there are other gases, such as the carbonic, sulphurous, and hydrochlorous acids, which are also present, and sometimes in great volume. The experiments of Faraday and others have shown that all these gases may be condensed into liquids by pressure. At temperatures of from 30° to 50° Fahr. the pressure required for this purpose varies from 15 to 50 atmospheres; and this amount of pressure we may regard as very insignificant in the operations of nature. A column of Vesuvian lava that would reach from the lip of the crater to the level of the sea, must be equal to about 300 atmospheres; so that, at depths which may be termed moderate in the interior of the crust of the earth, the gases may be condensed into liquids, even at very high temperatures. The method employed to reduce some of these gases to a liquid state is, to confine the materials, from the mutual action of which they are evolved, in tubes hermetically sealed,

* Tyndall: Heat as a Mode of Motion. 1863, p. 126.

so that the accumulated pressure of the vapour, as it rises and expands, may force some part of it to assume the liquid state. A similar process may, and indeed must, frequently take place in subterranean caverns and fissures, or even in the pores and cells of many rocks; by which means, a much greater store of expansive power may be *packed* into a small space than could happen if these vapours had not the property of becoming liquid. For, although the gas occupies much less room in a liquid state, yet it exerts exactly the same pressure upon the sides of the containing cavity as if it remained in the form of vapour.

If a tube, whether of glass or other materials, filled with condensed gas, have its temperature slightly raised, it will often burst; for a slight increment of heat causes the elasticity of the gas to increase in a very high ratio. If a minute hole be bored in the tube, the liquid gas will become instantly aëriform, or, in the language of some writers, it flashes into vapour, and in rushing out often bursts the vessel. We have only to suppose certain rocks, permeated by these liquid gases (as porous strata are sometimes filled with water), to have their temperature raised some hundred degrees, and we obtain a power capable of lifting superincumbent masses of almost any conceivable thickness; while, if the depth at which the gas is confined be great, there is no reason to suppose that any other appearances would be witnessed by the inhabitants at the surface than vibratory movements and rents, since the gases, in making their way through fissured rocks or soft yielding strata, may be cooled and absorbed by water. For water has a strong affinity for several of the gases, and will absorb large quantities, with a very slight increase of volume. In such cases there may be no outburst at the surface, nor any obvious indication of subterranean change. The temperature, perhaps, or volume of springs may be augmented, and their mineral properties altered, but no volcanic explosion may be witnessed. Whether a permanent change of level may be expected to occur as a consequence or accompaniment of such generation and heating of gases in the interior of the earth's crust, will be considered in the sequel.

The volcano of Cotopaxi has been known to throw out, to

the distance of 8 or 9 miles, a mass of rock about 100 cubic yards in volume, and there is no difficulty in understanding how the most solid substances which oppose the upward passage of the exploding gases may be reduced to small fragments, or even to dust, such as we see hurled to the height of many miles into the air by the volcano. In such cases we may suppose a continuous column of liquid lava mixed with *red-hot* or *white-hot water* (for water may exist in that state, as Professor Bunsen reminds us, under pressure), and this column may have a temperature regularly increasing downwards. A disturbance of equilibrium may first bring on an eruption near the surface, by the expansion and conversion into gas of entangled water and other constituents of what we call lava, so as to occasion a diminution of pressure. More steam would then be liberated, carrying up with it jets of melted rock, which being hurled up into the air may fall in showers of ashes on the surrounding country, and at length, by the arrival of lava and water more and more heated at the orifice of the duct or the crater of the volcano, expansive power may be acquired sufficient to expel a massive current of lava. After the eruption has ceased, a period of tranquillity succeeds, during which fresh accessions of heat are communicated from below, and additional masses of rock fused by degrees. At length the conditions required for a new outburst are obtained, and another cycle of similar changes is renewed.

Mr. Scrope suggested, so long ago as 1825,* that liquid lava owed its mobility not so much to simple heat as to the interstitial water contained in the crystalline or semi-crystalline matter of the lava, and that the crystals observable in lava, after cooling and hardening, existed there in a more or less complete form previously to emission. This theory, founded on the texture of the lava observed by Mr. Scrope from the eruption of Vesuvius in 1822, although much questioned, and even ridiculed, at the time, has now been accepted by a large number of geologists, and has derived much support from Scheerer's analysis of granite, by which he has proved that water is combined

* Volcanos, 1st ed., p. 22.

chemically with the crystalline matter of that rock in proportions sometimes amounting even to ten per cent.; and also that the different component minerals of this and some other plutonic rocks have become solid one after the other.

Access of water to volcanic foci.—In former editions, I suggested that if the accumulation of heat be granted as succesively developed in different parts of the earth's shell, we may readily conceive that the waters of lakes and seas might gain access to the fluid lava during earthquakes, large bodies of water being occasionally engulphed, and then, when the sides of the fissures closed again with violence (see page 125), the steam generated by contact of the water with the heated subterranean fluid might not escape by the same rents, but might rush out with lava from some distinct and perhaps habitual volcanic openings.

Mr. Scrope, in the preface to the last edition of his 'Volcanos' (1871), has objected that the opening of rents by earthquakes and the possible access thereby obtained by bodies of salt or fresh water to subterranean masses of lava would be the effect rather than the cause of volcanic action. I admit there is much force in this argument, for I never considered such sudden contact of water to be the primary cause of the volcano. But, nevertheless, I still think that there may be an intimate connection between an abundance of active volcanic vents and the proximity of seas and lakes. When a combination of heat and compressed gases, such as we have above assumed (p. 224), has given rise to earthquakes, and rent and dislocated the superficial crust, the occasional engulphment of overlying bodies of salt and fresh water may greatly add to the violence and frequency of the explosions.

The experiments and observations of the most eminent chemists have gradually removed, one after another, the objections which were first offered to the doctrine that the salt water of the sea plays a leading part in most volcanic eruptions. Sir H. Davy observed that the fumes which escaped from the Vesuvian lava deposited common salt.* M. Gay-Lussac, although he avowed his opinion that the decomposition of water contributed largely to volcanic action,

* Davy, Phil. Trans. 1828, p. 244.

called attention, nevertheless, to the supposed fact, that hydrogen had not been detected in a separate form among the gaseous products of volcanos; nor could it, he said, be present; for, in that case, it would be seen inflamed in the air by the red-hot stones thrown out during an eruption.* But M. Abich remarked, on the other hand, 'that although it be true that vapour illuminated by incandescent lava has often been mistaken for flame,' yet he had clearly detected the flame of hydrogen in the eruption of Vesuvius in 1834.†

In the memoir above alluded to, M. Gay-Lussac expressed doubt as to the presence of sulphurous acid; but the abundant disengagement of this gas during eruptions has been since ascertained: and thus all difficulty in regard to the general absence of hydrogen in an inflammable state is removed; for, as Dr. Daubeny suggests, the hydrogen of decomposed water may unite with sulphur to form sulphuretted hydrogen gas, and this gas will then be mingled with the sulphurous acid as it rises to the crater. It is shown by experiment, that these gases mutually decompose each other when mixed where steam is present; the hydrogen of the one immediately uniting with the oxygen of the other to form water, while the excess of sulphurous acid alone escapes into the atmosphere. Sulphur is at the same time precipitated.

This explanation is sufficient; but it may also be observed that the flame of hydrogen would rarely be visible during an eruption; as that gas, when inflamed in a pure state, burns, with a very faint blue flame, which even in the night could hardly be perceptible by the side of red-hot and incandescent cinders. Its immediate combination with oxygen to form water when inflamed in the atmosphere, might also account for its not appearing in a separate form.

The observations of Bunsen in Iceland in 1844, of St. Claire Deville on Vesuvius in 1855 and 1861, and of Fouqué on Santorin in 1866, have proved that there is an abundant escape of hydrogen, both in a free state and in combination with other substances, during eruptions; and the two last-

* Ann. de Chim. et de Phys. tom. xxii.

† Phénom. Géol. &c. p. 3.

mentioned chemists have succeeded in demonstrating the perfect accordance of the chemical composition of the products of volcanic eruptions, both gaseous and solid, with the doctrine that salt water has been largely present in the volcanic foci. It had been asked why then are there no salts of magnesia in volcanic fumeroles? They reply that these salts are readily decomposable by hot steam, and that when water and heat are present they produce hydrochloric acid and magnesia. That acid is found in the vapours which are disengaged from red-hot lava, and the magnesia which is not volatile is left behind in the lava itself, constituting one of its most important elements.* In like manner, the last-mentioned French chemists have shown that common salt can be resolved into its elements by hot steam alone, which Gay-Lussac had thought impossible.

M. Fouqué affirms that in the eruption of Etna which he witnessed in 1865, the gaseous emanations agreed in kind with those which we might have looked for if large bodies of sea-water had gained access to reservoirs of subterranean lava, and if they had been decomposed and expelled with the lava; and more than this, he calculated that the quantity of aqueous vapour was relatively to other gases in due proportion—that there was a daily emission from the several vents which were open on Etna, of no less than 22,000 cubic metres of aqueous vapour.

The presence of nitrogen among the gases evolved from craters in eruption, and in the waters of thermal springs, has been another subject of enquiry and discussion. Sir H. Davy, in his memoir on the 'Phenomena of Volcanos,' remarks, that there was every reason to suppose in Vesuvius the existence of a descending current of air; and he imagined that subterranean cavities which threw out large volumes of steam during the eruption, might afterwards, in the quiet state of the volcano, become filled with atmospheric air.† The presence of ammoniacal salts in volcanic emanations, and of ammonia (which is in part composed of nitrogen) in

* Fouqué, Rapport sur les Phénomènes Chimiques. Eruption of Etna in 1865, p. 57.

† Phil. Trans. 1828.

lava, favours greatly the notion of air as well as water being deprived of its oxygen in the interior of the earth. Dr. Daubeny suggests that water containing atmospheric air may descend from the surface of the earth to the volcanic foci, and that the same process of combustion by which water is decomposed may deprive such subterranean air of its oxygen. In this manner great quantities of nitrogen may be evolved. The presence of vast numbers of siliceous cases of infusoria in the tuff covering Pompeii, and composed of matter ejected from Vesuvius, has already been alluded to. (Vol. I. p. 645.) They prove that water and mud have penetrated downwards from the surface into rents and caverns in the interior, and have then been thrown out again during volcanic eruptions.

Chemical action.—When Sir H. Davy first discovered the metallic bases of the earths and alkalies, he threw out the idea that stores of those metals might abound in an unoxidised state in the subterranean regions to which water must occasionally penetrate. Whenever this happened, gaseous matter would be set free, the metals would combine with the oxygen of the water, and sufficient heat might be evolved to melt the surrounding rocks. This hypothesis was at first very favourably received both by the chemist and the geologist: for silica, alumina, lime, soda, and oxide of iron—substances of which lavas are principally composed—would all result from the contact of the elements above alluded to with water. But when Davy failed to detect, during an eruption of Vesuvius, any hydrogen among the gaseous products evolved from the crater, he was disposed to renounce or to attach but little importance to his theory.

We have seen (p. 227) that it is now ascertained that hydrogen is disengaged during eruptions in large quantities, although, according to M. Fouqué, there are always some hydrocarbons mixed with the free hydrogen.* The same chemist remarks, that to explain the disengagement of heat during the last eruption of Etna, we should require a mass of sodium of at least 7,000,000 cubic metres, and therefore

* Fouqué, Rapport sur les Phénomènes Chimiques de l'Éruption de l'Etna en 1865, p. 80.

the quantity of alkaline metals beneath all the active volcanos, which have given rise to each in a long series of eruptions, would be incredibly great. M. Fouqué is satisfied with the hypothesis of a subterranean sheet of fluid lava, to which water occasionally may gain access, central heat being invoked as the power by which the lower parts of the earth's crust are retained in a melted state, and no explanation being attempted by him of the shifting of the volcanic force from one part of the earth's envelope to another.

What we have now said of the manner in which aqueous and other gases may be expected to operate mechanically and chemically on the crust of the earth, whenever water and various acids, stored up in caverns and fissures at great depths, have their temperatures raised, must satisfy the reader that it is only necessary, in order to explain the action of volcanos, to discover some cause which is capable of bringing about such a concentration of heat as may melt, one after the other, certain portions of the solid crust so as to form seas, lakes, or oceans of subterranean lava. This being granted, the greater part of the crust at any given time will contain at various depths sheets of such lava slowly parting with their heat, some semi-fluid, others more or less viscous, and others beginning to consolidate or crystallise. The general state, therefore, of the exterior of the planet would be that of a mass once heated, and which has been gradually cooling; but in certain spots, namely, the regions of active volcanos, regions very limited and exceptional as regards the whole surface, the heat will be sustained near the surface, and will occasionally manifest its intensity in the operations of the volcano and the earthquake.

Mr. Scrope remarks that the absence of volcanic vents in the interior of continents 'would result from the generally admitted fact that the continental tracts have been elevated above the sea-level by internal expansions of deeply-seated matter which could not force its way outwards; or where, in the words of Mr. Mallet, uncompleted efforts to establish a volcano have occurred.'* He considers that there is no proof of any general fluidity of the central nucleus, and that we

* Volcanos: Preface, p. 8. 1872.

cannot safely speculate on the existence in the crust of the globe of more than pockets or local seas and lakes of melted matter. Without pretending to explain in what manner the heated steam may generally gain access to such lava, or how in the course of geological ages it has shifted its principal points of concentration, he remarks that the very different powers of conducting heat in the incumbent rocks must in the course of time cause some of these lavas to part with more heat than others, so that the state of the interior cannot remain constantly the same.

Mr. Babbage in 1834, and Sir J. Herschel independently in the same year,* suggested that differences of temperature in the earth's crust analogous to those above mentioned might be brought about by denudation removing large masses of matter from one part of the crust of the globe, and depositing them in some other region, often far distant, on the floor of the ocean. By this transfer the outward escape of heat would be facilitated in one place where the denuded crust had become thinner, and checked in another where the deposition of new matter had added to its thickness, the planes of the subterranean isothermals or surfaces of equal temperature being thus made to vary. During such changes it is suggested by Mr. Scrope that the direction of the internal heat would be altered, and might sometimes flow laterally towards those avenues for its outward escape which are from time to time afforded by volcanic fissures and earthquake disturbances.

That beneath the Andes and other great areas of active volcanos there are reservoirs, at the depth of some miles, of lava in a constant state of fusion, cannot be doubted from what we have already stated (pp. 90 and 202). All the observed phenomena from which the existence of central fluidity has been inferred are reconcilable with the occurrence at certain depths of such masses of lava in the earth's crust as we have admitted to be probable, and which, even if they equalled the Atlantic and Pacific Oceans in volume, may hold a very subordinate place in the solid shell of the planet.

* Proc. Geol. Soc., Vol. II., p. 75 and p. 550.

The connection of earthquakes with a flexible crust overlying such reservoirs of melted rock is quite conceivable.

Flexibility of the earth's crust.—The inhabitants of Stromboli, who are mostly fishermen, are said to make use of that volcano as a weather-glass, the eruptions being comparatively feeble when the sky is serene, but increasing in turbulence during tempestuous weather, so that in winter the island often seems to shake from its foundations. Mr. P. Scrope, after calling attention to these and other analogous facts, first started the idea (as long ago as the year 1825) that the diminished pressure of the atmosphere, the concomitant of stormy weather, may modify the intensity of the volcanic action. He suggests that where liquid lava communicates with the surface, as in the crater of Stromboli, it may rise or fall in the vent on the same principle as mercury in a barometer; because the ebullition or expansive power of the steam contained in the lava would be checked by every increase, and augmented by every diminution of weight. In like manner, if a bed of liquid lava be confined at an immense depth below the surface, its expansive force may be counteracted partly by the weight of the incumbent rocks, and also in part by atmospheric pressure acting contemporaneously on a vast superficial area. In that case, if the upheaving force increase gradually in energy, it will at length be restrained by only the slightest degree of superiority in the antagonist or repressive power, and then the equilibrium may be suddenly destroyed by any cause, such as an ascending draught of air, which is capable of depressing the barometer. In this manner we may account for the remarkable coincidence so frequently observed between the state of the weather and subterranean commotions, although it must be admitted that earthquakes and volcanic eruptions react in their turn upon the atmosphere, so that disturbances of the latter are generally the consequences rather than the forerunners of volcanic disturbances.*

From an elaborate catalogue of the earthquakes experienced in Europe and Syria during the last fifteen centuries, M.

* Scrope on Volcanos, pp. 58-60.

Alexis Perrey concludes that the number which happen in the winter season preponderate over those which occur in any one of the other seasons of the year, there being, however, some exceptions to this rule, as in the Pyrenees. Curious and valuable as are these data, M. d'Archiac justly remarked, in commenting upon them, that they are not as yet sufficiently extensive or accordant in different regions, to entitle us to deduce any general conclusions from them respecting the laws of subterranean movements throughout the globe.*

M. Perrey has also, in a later report of earthquakes (1863), inferred, as the result of 10,000 observations on the earthquakes of the first half of the present century, that they occur more frequently and with more violence when the moon is in perigee, or nearest the earth, than at other periods, when that satellite being less near is exerting a minor degree of force, or less strain upon the solid crust of our planet. In like manner he thinks he has detected a relation between the frequency of earthquakes and our winter and summer solstices, the greatest number of shocks occurring in perihelion when the sun is nearest, and the least number in aphelion when it is farthest from the earth.† On this subject Sir John Herschel remarks, 'The action of the sun and moon, though it cannot produce a tide in the solid crust of the earth, tends to do so, and were it fluid would produce it. It does therefore, in point of fact, bring the solid portions of the earth's surface into a state alternately of strain and compression.' ‡

Electricity and magnetism considered as sources of volcanic heat.—The popular notion of a central fluid nucleus, on which a thin outer shell is floating, has diverted the speculations of the physicist and natural philosopher from attempting to invent some theory which might explain the continual shifting of the points of the chief development of heat from one part of the shell to another, leaving large portions previously in a state of fusion to cool and consolidate. Soon after the first great discoveries of Oersted in electro-

* D'Archiac, Hist. des Progrès de la Géol. 1847, vol. i. pp. 605–610.

† Alexis Perrey, Propositions sur les Tremblements de Terre, 1863.

‡ Herschel, Familiar Lecture on Scientific Subjects, 1866, p. 45.

magnetism, Ampère suggested that all the phenomena of the magnetic needle might be explained by supposing currents of electricity to circulate constantly in the shell of the globe in directions parallel to the magnetic equator. This theory has acquired additional consistency the farther we have advanced in science; and according to the experiments of Mr. Fox, on the electro-magnetic properties of metalliferous veins, some trace of electric currents seems to have been detected in the interior of the earth.*

Some philosophers ascribe these currents to the chemical action going on in the superficial parts of the globe to which air and water have the readiest access; while others refer them, in part at least, to thermo-electricity excited by the solar rays on the surface of the earth during its rotation; successive parts of the atmosphere, land, and sea being exposed to the influence of the sun, and then cooled again in the night. That this idea is not a mere speculation, is proved by the correspondence of the diurnal variations of the magnet with the apparent motion of the sun; and by the greater amount of variation in summer than in winter, and during the day than in the night.

Recent discoveries of a connection between periodical changes in the spots of the sun and variations in terrestrial magnetism, have suggested the idea that solar magnetism has a powerful influence on the earth's crust. According to Sir John Herschel, the cycle of change, including the periods when the spots are most abundant and large, and those when they are least apparent, occupies rather more than 11 years, so that there are 9 of these cycles in a century. So late as September 1, 1859, when the spots were very large, 'two observers, far apart and unknown to each other, were viewing them with powerful telescopes, when suddenly, at the same moment of time, both saw a strikingly brilliant luminous appearance, like a cloud of light, far brighter than the general surface of the sun, break out in the immediate neighbourhood of one of the spots, and sweep across and beside it. It occupied about five minutes in its passage, and in that time travelled over a space on the sun's surface which could not

* Phil. Trans. 1830, p. 399.

be estimated at less than 35,000 miles. A magnetic storm was in progress at the time. From August 28 to September 4 many indications showed the earth to have been in a perfect convulsion of electro-magnetism.'

At Kew, where there are self-registering magnetic instruments, by which the positions of three magnetic needles are recorded by photography, it was found that all three had made a strongly marked jerk from their former positions at the very moment when the bright light had been seen crossing the solar spot. It would appear that the magnetic influence had reached the earth at the same time with the light.

'By degrees, accounts began to pour in of great Auroras seen on the nights of those days, not only in these latitudes, but at Rome, in the West Indies, on the tropics within 18° of the equator (where they hardly ever appear), nay, what is still more striking, in South America and in Australia, where, at Melbourne, on the night of the 2nd of September, the greatest Aurora ever seen there made its appearance. These Auroras were accompanied by unusually great electro-magnetic disturbances in every part of the world. In many places the telegraphic wires struck work. At Washington and Philadelphia, in America, the telegraph signal-men received severe electric shocks. At a station in Norway the telegraphic apparatus was set fire to; and at Boston, in North America, a flame of fire followed the pen of Bain's electric telegraph, which writes down the message upon chemically prepared paper.'*

The passage of this electro-magnetic force from the sun to our globe may, perhaps, be one of the principal means by which heat lost by radiation into space may be restored to the planet; and we may easily imagine that at successive geological periods, when new mountain chains have been thrown up and old ones have been removed by subsidence or denudation, when even oceans and continents have changed places, the circulation of electro-magnetic currents and the local concentration of heat due to them may affect new parts of the exterior of the planet. It is scarcely possible to exag-

* Herschel, Familiar Lectures on Scientific Subjects, 1866, p. 80.

gerate the amount of action and reaction to which the cause here alluded to may give rise. 'The silent and slow operation of electricity as a chemical agent is more important,' says Davy, 'in the economy of nature than its grand and impressive operation in lightning and thunder. It may be considered, not only as directly producing an infinite variety of changes, but as influencing almost all which take place; it would seem, indeed, that chemical attraction itself is only a peculiar form of the exhibition of electrical attraction.'*

Thermo-electricity may be generated by great inequalities of temperature, arising from a partial distribution of volcanic heat. Wherever, for example, masses of rock occur of great horizontal extent, and of considerable depth, which are at one point in a state of fusion (as beneath some active volcano); at another, red-hot; and at a third, comparatively cold—strong thermo-electric action may be excited, and subterranean electric currents, if once excited, may melt rock or possess the decomposing power of the voltaic pile.

But the difficulties we encounter when we attempt to form a chemical theory of volcanos, are almost insurmountable, in consequence of our inability to test experimentally the mode in which different substances, solid, fluid, or gaseous, would behave under conditions of pressure and temperature wholly different from those experienced at the surface. A simple difference in the amount of heat may cause all the chemical affinities of bodies to be essentially modified. Mercury does not combine with oxygen at ordinary temperatures, but combines with it at its boiling point, and then gives it off again at an incipient red heat. Here we have three different states of chemical affinity, within the limits of a few hundred degrees; and who would dare assert, that at this last phase of separation, the chemical action between these two elements ceases definitely and for all higher temperatures? But what is true of mercury and oxygen, is likewise true *mutatis mutandis* for all other elements.

That there should be so much heat and chemical action and reaction, developed in certain parts of the interior of the

* Consolations in Travel, p. 271.

earth, is not so wonderful as the ordinary repose and inertness of the internal mass. When we consider the combustible nature of the elements of the earth, so far as they are known to us—the facility with which their compounds may be decomposed and made to enter into new combinations—the quantity of heat which they evolve during these processes; when we recollect the expansive power of steam, and call to mind the number of explosive and detonating compounds which have been already discovered, we may be allowed to share the astonishment of Pliny, that a single day should pass without a general conflagration:—'Excedit profectò omnia miracula, ullum diem fuisse quo non cuncta conflagrarent.'*

Causes of permanent elevation and subsidence of land.—The position of the fossiliferous and other rocks in the earth's crust has enabled the geologist to infer that some of these rocks have been lifted up to the height of several miles above the level at which they were originally formed in the bed of the ocean, and also that there have been gradual subsidences of rocks to a vast amount below the levels which they once occupied. These great movements have been caused by subterranean or volcanic heat, which has affected different parts of the earth in succession. The existing mountain chains are of different ages, and few of them owe the whole of their present conformation to the movements experienced in a single epoch. The forces, whether in an upward or downward direction, to which they are due, and by which the varying position of continents and oceanic basins has in the course of ages been determined, have evidently shifted their points of chief development from one region to another, like the volcano and the earthquake, and are in fact all the results of the same internal operations, to which heat, electricity, magnetism, and chemical affinity give rise.

Experiments were made in America, by Colonel Totten, to ascertain the ratio according to which some of the stones commonly used in architecture expand with given increments of heat.† It was found impossible, in a country where the

* Hist. Mundi, lib. ii. c. 107.

† Silliman's American Journ. vol. xxii. p. 136. The application of these results to the theory of earthquakes was first suggested to me by Mr. Babbage.

annual variation of temperature was more than 90° Fahr., to make a coping of stones, 5 feet in length, in which the joints should fit so tightly as not to admit water between the stone and the cement; the annual contraction and expansion of the stones causing, at the junctions, small crevices, the width of which varied with the nature of the rock. It was ascertained that fine-grained granite expanded with 1° Fahr. at the rate of ·000004825; white crystalline marble ·000005668; and red sandstone ·000009532, or about twice as much as granite.

Now, according to this law of expansion, a mass of sandstone, a mile in thickness, which should have its temperature raised 200° Fahr. would lift a superimposed layer of rock to the height of 10 feet above its former level. But, suppose a part of the earth's crust, 50 miles in thickness and equally expansible, to have its temperature raised 600° or 800°, this might produce an elevation of between 1,000 and 1,500 feet. The cooling of the same mass might afterwards cause the overlying rocks to sink down again and resume their original position. By such agency we might explain the gradual rise of part of Scandinavia or the subsidence of Greenland.

It is also possible that as the clay in Wedgwood's pyrometer contracts, by giving off its water, and then, by incipient vitrification; so, large masses of argillaceous strata in the earth's interior may shrink, when subjected to heat and chemical changes, and allow the incumbent rocks to subside gradually.

Moreover, if we suppose that lava cooling slowly at great depths may be converted into various granite rocks, we obtain another source of depression; for, according to the experiments of Deville and the calculations of Bischoff, the contraction of granite when passing from a melted or plastic to a solid and crystalline state must be more than 10 per cent.*—though Mr. David Forbes is of opinion from experiments made by him on a larger scale that this percentage is too high.†

Dr. Bischoff has also remarked, that when silicates,

* Bulletin de la Soc. Géol. 2nd series, vol. iv. p. 1312.

† Chemical News, Oct. 23, 1868.

which enter so largely into the composition of the oldest rocks —gneiss, mica-schist, clay-slate, and others—are percolated by carbonic acid gas, which is of almost universal occurrence at great depths, they must be continually decomposed. When that happens, the carbonates formed by the new combinations thence arising must often augment the volume of the altered rocks. This increase of bulk, he says, must sometimes give rise to a mechanical force of expansion capable of uplifting the incumbent crust of the earth, and the same force may act laterally, so as to compress, dislocate, and tilt the strata on each side of a mass in which the new chemical changes are developed. The same eminent German chemist has attempted to calculate the exact amount of distention to which the new mineral products thus formed may give rise by adding to the volume of the rocks.

If once some parts of the earth's crust are shattered, as in regions of earthquakes, and reservoirs of melted stone and heated vapours have acquired force enough to uplift the incumbent mass, we may easily conceive how the country may remain permanently upheaved. For in some places the fractured rocks below may have assumed an arched form, or lava may have been driven into fissures, in which it may consolidate, and afford an enduring support to the foundations of the newly raised strata.

The sudden subsidence of limited areas of land may be occasioned by subterranean caverns giving way, when gases are condensed, or when they escape through newly-formed crevices. The subtraction, moreover, of matter from certain parts of the interior, by the flowing of lava, and of mineral springs, must, in the course of ages, cause vacuities below, so that the undermined surface may at length fall in or be slowly depressed. In this manner we may, perhaps, explain the geographical connection which seems to exist between areas of elevation and of subsidence, a deep sea being often contiguous to elevated land.

Balance of dry land, how preserved.—It will appear, from the historical details above given, that the force of subterranean movement, whether intermittent or continuous, whether with or without disturbance, does not operate at random, but is

developed in certain regions only; and although the alterations produced during the time required for the occurrence of a few volcanic eruptions may be inconsiderable, we can hardly doubt that, during the ages necessary for the formation of large volcanic cones, composed of thousands of lava currents, shoals might be converted into lofty mountains, and low lands into deep seas.

In a former chapter (Vol. I. p. 321), I have stated that aqueous and igneous agents may be regarded as antagonist forces; the aqueous labouring incessantly to reduce the inequalities of the earth's surface to a level, while the igneous are equally active in renewing the unevenness of the surface. By some geologists it has been thought that the levelling power of running water was opposed rather to the *elevating* force of earthquakes than to their action generally. This opinion is, however, untenable; for the sinking down of the bed of the ocean is one of the means by which the gradual submersion of land is prevented. The depth of the sea cannot be increased at any one point without a universal fall of the waters, nor can any partial deposition of sediment occur without the displacement of a quantity of water of equal volume, which will raise the sea, though in an imperceptible degree, even to the antipodes. The preservation, therefore, of the dry land may sometimes be effected by the subsidence of part of the earth's crust (that part, namely, which is covered by the ocean), and in like manner an upheaving movement must often tend to destroy land; for if it render the bed of the sea more shallow, it will displace a certain quantity of water, and thus tend to submerge low tracts.

If the dimensions of the planet have remained uniform during the period which we contemplate in geology, it would be necessary to suppose that the amount of depression caused by subterranean heat must exceed that of elevation, otherwise there would not be a perpetual restoration of those inequalities of the earth's surface which the levelling power of water tends to efface. It would be otherwise if the action of volcanos and mineral springs were suspended; for then the forcing outwards of the earth's envelope ought to be no more than equal to its sinking in.

To understand this proposition more clearly, it must be borne in mind, that the deposits of rivers and currents probably add as much to the height of submerged lands which are rising, as they take from those which have risen. Suppose a large river to bring down sediment to a part of the ocean 2,000 feet deep, and that the depth of this part is gradually reduced by the accumulation of sediment till only a shoal remains, covered by water at high tides; if now an upheaving force should uplift this shoal to the height of 2,000 feet, the result would be a mountain 2,000 feet high. But had the movement raised the same part of the bottom of the sea before the sediment of the river had filled it up; then, instead of changing a shoal into a mountain 2,000 feet high, it would only have converted a deep sea into a shoal.

It appears, then, that the operation of the volcanic or subterranean forces is often such as to cause the levelling power of water to counteract itself; and, although the idea may appear paradoxical, we may be sure, wherever we find hills and mountains composed of stratified deposits, that such inequalities of the surface would have had no existence if water, at some former period, had not been labouring to reduce the earth's surface to one level.

But, besides the transfer of matter by running water from the continents to the ocean, there is a constant transportation from below upwards, by mineral springs and volcanic vents. As mountain masses are, in the course of ages, created by the pouring forth of successive streams of lava, so stratified rocks of great extent originate from the deposition of carbonate of lime, and other mineral ingredients, with which springs are impregnated. The surface of the land, and portions of the bottom of the sea, being thus raised, the external accessions due to these operations would cause the dimensions of the planet to enlarge continually, if the amount of depression of the earth's crust were no more than equal to the elevation. In order, therefore, that the mean diameter of the earth should remain uniform, and the unevenness of the surface be preserved, it is necessary that the amount of subsidence should be in excess. And such a predominance of depression is far from improbable, on mechanical prin-

ciples, since every upheaving movement must be expected either to produce caverns in the mass below, or to cause some diminution of its density. Vacuities must, also, arise from the subtraction of the matter poured out from volcanos and mineral springs, or from the contraction of argillaceous masses by subterranean heat; and the foundations having been thus weakened, the earth's crust, shaken and rent by reiterated convulsions, must, in the course of time, fall in.

It seems, therefore, to be rendered probable, by the views above explained, that the constant repair of the land, and the subserviency of our planet to the support of terrestrial as well as aquatic species, are secured by the elevating and depressing power of causes acting in the interior of the earth; which, although so often the source of death and terror to the inhabitants of the globe—visiting in succession every zone, and filling the earth with monuments of ruin and disorder—are nevertheless the agents of a conservative principle above all others essential to the stability of the system.

Recapitulation of Chapters XXXII. and XXXIII.—I will now recapitulate the principal conclusions arrived at in this and in the preceding chapter.

1. The primary causes of the volcano and the earthquake are to a great extent the same, and connected with the development of heat and chemical action at various depths in the interior of the globe.

2. Volcanic heat has been supposed by many to be the result of the high temperature which belonged to the whole planet when it was in a state of igneous fusion, a temperature which they suppose to have been always diminishing and still to continue to diminish by radiation into space, but recent enquiries have suggested that the apparent loss of heat may arise from the successive local development of volcanic action.

3. The spheroidal figure of the earth does not of necessity imply a universal and simultaneous fluidity, in the beginning; for whatever may have been the original shape of our planet, the statical figure must have been assumed, if sufficient time be allowed, by the gradual operation of the centrifugal force, acting on yielding materials brought successively within its action by aqueous and igneous causes.

4. The late Mr. Hopkins inferred that the precessional motion of the earth could not be such as it now is, unless the solid crust was at least from 800 to 1,000 miles thick; but the precessional movement is consistent with the supposition of a much greater thickness, and even with the general solidity of the entire globe, provided that lakes or oceans of melted matter, which may be distributed through it, are so enclosed as to move with the solid portion.

5. The heat in mines and Artesian wells increases as we descend, but not in a uniform ratio, in different regions. If the heat were continued downwards at the same rate, it would imply such an elevation of temperature in the central nucleus as must instantly fuse the crust.

6. The hypothesis of a central fluid and of a thin solid shell resting or floating upon it, is inconsistent with the absence of internal tides, such as would make the lava ebb and flow in volcanic craters during eruptions.

7. The hypothesis of a change in the axis of rotation of a supposed solid envelope, made to slide over an internal fluid nucleus in consequence of the transfer of sediment from higher to lower, or from lower to higher, latitudes, is untenable, because the excess of matter displaced and carried in one direction would be extremely slight, and the oblato-spheroidal figure of the earth would render such freedom of motion impossible.

8. Assuming that there were good astronomical grounds for inferring the original fluidity of the planet, such pristine fluidity need not affect the question of volcanic heat, for the volcanic action of successive periods belongs to a state of the globe long posterior to its origin, and implies the melting of different parts of the solid crust one after the other.

9. The quantity of lava, fluid at any one time in the earth's crust, although it may be of importance in reference to superficial changes, such as the formation of mountain chains, or lines of volcanic vents, or regions of earthquakes, may still be quite insignificant in relation to the size of an external shell having a thickness of 50 miles.

10. The supposed greater energy of the volcanic forces in the remoter periods is by no means borne out by geological

observations on the quantity of lava produced by single eruptions in those several periods.

11. The old notion that the crystalline rocks, whether stratified or unstratified, such as granite and gneiss, were produced in the lower parts of the earth's crust at the expense of a central nucleus slowly cooling from a state of fusion by heat, has had to be given up, now that granite is found to be of all ages, and now that we know the metamorphic rocks to be altered sedimentary deposits implying the denudation of a previously solidified crust.

12. The powerful agency of steam or aqueous vapour in volcanic eruptions leads us to compare its power of propelling lava to the surface with that which it exerts in driving up water in the pipe of an Icelandic Geyser. Various gases also, rendered liquid by pressure at great depths, may aid in causing volcanic outbursts, and in fissuring and convulsing the rocks during earthquakes.

13. The latest chemical observations on the products of recent eruptions, favour the doctrine that large bodies of salt water gain access to the volcanic foci. Although this may not be the primary cause of volcanic eruptions, which are probably due to the aqueous vapour intimately mixed with molten rock, yet when once the crust has been shattered, and a communication been opened with the surface, the force and frequency of eruptions may depend in some measure on the proximity of large overlying bodies of water.

14. The flexibility of certain parts of the earth's crust, as deduced from observations on earthquakes, may imply the continuous existence of vast reservoirs of melted matter beneath the surface, but such nevertheless as might hold a very subordinate place in the earth's crust.

15. The existence of electrical currents in the earth's crust, and the changes in direction which they may undergo after great geological revolutions in the position of mountain chains and of land and sea, the connection also of solar and terrestrial magnetism, and of this last with electricity and chemical action, may help us to conceive such a cycle of change as may restore to the planet the heat supposed to be lost by radiation into space.

16. The permanent elevation and subsidence of land now observed, and which have been going on throughout past geological ages, may be connected with the expansion and contraction of parts of the solid crust, some of which have been cooling from time to time, while others have been gaining fresh accessions of heat.

17. In the preservation of the average proportion of land and sea, the igneous agents exert a conservative power, restoring the unevenness of the surface, which the levelling power of water in motion would tend to destroy. If the diameter of the planet remains always the same,* the downward movements of the crust must be somewhat in excess, to counterbalance the effect of volcanos and mineral springs, which are always bringing up materials from the interior of the earth and pouring them out at the surface, so as to raise its level. Subterranean movements, therefore, however destructive they may be during great earthquakes, are essential to the well-being of the habitable surface, and even to the very existence of terrestrial species.

* See vol. i. p. 304.

BOOK III.

CHANGES OF THE ORGANIC WORLD NOW IN PROGRESS.

CHAPTER XXXIV.

LAMARCK ON THE TRANSMUTATION OF SPECIES.

DIVISION OF THE SUBJECT—EXAMINATION OF THE QUESTION, WHETHER SPECIES HAVE A REAL EXISTENCE IN NATURE?—IMPORTANCE OF THIS QUESTION IN GEOLOGY—SKETCH OF LAMARCK'S ARGUMENTS IN FAVOUR OF THE TRANSMUTATION OF SPECIES, AND HIS CONJECTURES RESPECTING THE ORIGIN OF EXISTING ANIMALS AND PLANTS—HIS THEORY OF THE TRANSFORMATION OF THE ORANG-OUTANG INTO THE HUMAN SPECIES.

HITHERTO we have been occupied, from Chap. XV. to Chap. XXXIII., with the consideration of the changes brought about on the earth's surface, within the period of human observation, by inorganic agents; such, for example, as rivers, marine currents, volcanos, and earthquakes. But there is another class of phenomena relating to the organic world, which have an equal claim on our attention, if we desire to obtain possession of all the preparatory knowledge respecting the existing course of nature, which may be available in the interpretation of geological monuments. It appeared from our preliminary sketch of the progress of the science, that the most lively interest was excited among its earlier cultivators, by the discovery of the remains of animals and plants in the interior of mountains frequently remote from the sea. Much controversy arose respecting the nature of these remains, the causes which may have brought them into so singular a position, and the want of a specific agreement between them and known animals and plants. To qualify ourselves to form just views on these curious questions, we must first study the present condition of the animate creation on the globe.

This branch of our enquiry naturally divides itself into two parts:—

First, we may consider the various meanings which have been attached to the term 'species,' and the question which has been raised whether each species has remained from its origin the same, only varying within certain fixed and defined limits, or whether a species may be indefinitely modified in the course of a long series of generations. This will lead us to examine into the dependence of each species of animal and plant on certain fluctuating and temporary conditions in the animate and inanimate world, and the consequent extinction of species one after the other, and the manner in which the places left vacant may be supplied by new animals and plants better fitted for the new conditions.

Secondly, we may consider the processes by which some individuals of certain species may occasionally become fossil, or be preserved in such a manner as to form part of the solid framework of the earth's crust, so that they may serve in after ages as monuments of the state of the living world at the time when they became fossil.

Before we can advance a step in our enquiry, we must endeavour to make up our minds as to the meaning which we attach to the term 'species.' This is even more necessary in geology than in the ordinary studies of the naturalist; for they who contend for the indefinite modifiability of species, admit, nevertheless, that a botanist or zoologist may reason as if the specific character were constant, because they confine their observations to a brief period of time. Just as the astronomer, in constructing his maps of the heavens, may proceed century after century as if the apparent places of the fixed stars remained absolutely the same, and as if no alteration were brought about by the proper motion of the sun; so, it is said, in the organic world, the stability of a species may be taken as absolute, if we do not extend our views beyond the narrow period of human history; but let a sufficient number of centuries elapse, to allow of important revolutions in climate, physical geography, and other circumstances, and the characters, say they, of the descendants of common parents may deviate indefinitely from their original type.

Now, if these doctrines be tenable, we are at once presented with a principle of incessant change in the organic world; and no degree of dissimilarity in the plants and animals which may formerly have existed, and are found fossil, would entitle us to conclude that they may not have been the prototypes and progenitors of the species now living. Accordingly MM. Lamarck and Geoffroy St. Hilaire declared their opinion in the beginning of the present century that there had been an uninterrupted succession in the animal kingdom, effected by means of generation, from the earliest ages of the world up to the present day, and that the ancient animals whose remains have been preserved in the strata, however different, may nevertheless have been the ancestors of those now in being. In order to explain the facts and reasoning by which this theory was originally supported, I cannot do better than offer the reader a rapid sketch of the proofs which were regarded by Lamarck as confirmatory of his views, shared as they were to a great extent by his contemporary, Geoffroy St. Hilaire.*

Lamarck's arguments in favour of the transmutation of species.—The name of 'species,' observes Lamarck, has been usually applied to 'every collection of similar individuals produced by other individuals like themselves.' † The defini-

* I have reprinted in this chapter, word for word, my abstract of Lamarck's doctrine of transmutation as drawn up by me in 1832 in the first edition of the 'Principles of Geology,' vol. ii. chap. i. I have thought it right to do this in justice to Lamarck, in order to show how nearly the opinions taught by him at the commencement of this century resembled those now in vogue amongst a large body of naturalists respecting the indefinite variability of species, and the progressive development in past time of the organic world. The reader must bear in mind that when I made this analysis of the 'Philosophie Zoologique,' in 1832, I was altogether opposed to the doctrine that the animals and plants now living were the lineal descendants of distinct species only known to us in a fossil state: and it will be seen, by reference to p. 274, that, so far from exaggerating, I did not do justice to the arguments originally adduced by Lamarck and Geoffroy St. Hilaire, especially those founded on the occurrence of rudimentary organs. There is, therefore, no room for suspicion that my account of the Lamarckian hypothesis, written by me thirty-five years ago, derived any colouring from my own views tending to bring it more into harmony with the theory since promulgated by Darwin. The law of natural selection, by which the last-mentioned great naturalist has thrown so much new light on the origin of species, will be explained in the next and succeeding chapters.

† Phil. Zool. tom. i. p. 54. 1809.

tion, he admits, is correct; because every living individual bears a very near resemblance to those from which it springs. But this is not all which is usually implied by the term 'species;' for the majority of naturalists agree with Linnæus in supposing that all the individuals propagated from one stock have certain distinguishing characters in common, which will never vary, and which have remained the same since the creation of each species. Lamarck proposed, therefore, to amplify the received definition in the following manner. 'A species consists of a collection of individuals resembling each other, and reproducing their like by generation, so long as the surrounding conditions do not alter to such an extent as to cause their habits, characters, and forms to vary.'

In order to show the grounds for this limitation of the word 'species,' Lamarck entered upon the following line of argument:—The more we advance in the knowledge of the different organised bodies which cover the surface of the globe, the more our embarrassment increases to determine what ought to be regarded as a species, and still more how to limit and distinguish genera. In proportion as our collections are enriched, we see almost every void filled up, and all our lines of separation effaced; we are reduced to arbitrary determinations, and are sometimes fain to seize upon the slight differences of mere varieties, in order to form characters for what we choose to call a species; and sometimes we are induced to pronounce individuals but slightly differing and which others regard as true species, to be varieties.

The greater the abundance of natural objects assembled together, the more do we discover proofs that everything passes by insensible shades into something else; that even the more remarkable differences are evanescent, and that nature has, for the most part, left us nothing at our disposal for establishing distinctions, save trifling, and, in some respects, puerile peculiarities.

We find that many genera amongst animals and plants are of such an extent, in consequence of the number of species referred to them, that the study and determination

of these last has become almost impracticable. When the species are arranged in a series, and placed near to each other, with due regard to their natural affinities, they each differ in so minute a degree from those next adjoining, that they almost melt into each other, and are in a manner confounded together. If we see isolated species, we may presume the absence of some more closely connected, and which have not yet been discovered. Already are there genera, and even entire orders—nay, whole classes—which present an approximation to the state of things here indicated.

If, when species have been thus placed in a regular series, we select one, and then, making a leap over several intermediate ones, we take a second, at some distance from the first, these two will, on comparison, be seen to be very dissimilar; and it is in this manner that every naturalist begins to study the objects which are at his own door. He then finds it an easy task to establish generic and specific distinctions; and it is only when his experience is enlarged, and when he has made himself master of the intermediate links, that his difficulties and ambiguities begin. But while we are thus compelled to resort to trifling and minute characters in our attempt to separate species, we find a striking disparity between individuals which we know to have descended from a common stock; and these newly acquired peculiarities are regularly transmitted from one generation to another, constituting what are called *races*.

From a great number of facts, continues the author, we learn that in proportion as the individuals of one of our species change their situation, climate, and manner of living, they change also, by little and little, the consistence and proportions of their parts, their form, their faculties, and even their organisation, in such a manner that everything in them comes at last to participate in the mutations to which they have been exposed. Even in the same climate, a great difference of situation and exposure causes individuals to vary; but if these individuals continue to live and to be reproduced under the same difference of circumstances, distinctions are brought about in them which become in some degree essential to their existence. In a word, at the

end of many successive generations, these individuals, which originally belonged to another species, are transformed into a new and distinct species.*

Thus, for example, if the seeds of a grass, or any other plant which grows naturally in a moist meadow, be accidentally transported, first to the slope of some neighbouring hill, where the soil, although at a greater elevation, is damp enough to allow the plant to live; and if, after having lived there, and having been several times regenerated, it reaches by degrees the drier and almost arid soil of a mountain declivity, it will then, if it succeeds in growing, and perpetuates itself for a series of generations, be so changed that botanists who meet with it will regard it as a peculiar species.* The unfavourable climate in this case, deficiency of nourishment, exposure to the winds, and other causes, give rise to a stunted and dwarfish race, with some organ more developed than others, and having proportions often quite peculiar.

What nature brings about in a great lapse of time, we occasion suddenly by changing the circumstances in which a species has been accustomed to live. All are aware that vegetables taken from their birth-place, and cultivated in gardens, undergo changes which render them no longer recognisable as the same plants. Many which were naturally hairy become smooth, or nearly so; a great number of such as were creepers and trailed along the ground, rear their stalks and grow erect. Others lose their thorns or asperities; others, again, from the ligneous condition which characterised their stem in the hot climates, where they were indigenous, pass to the herbaceous; and, among them, some which were perennials become mere annuals. So well do botanists know the effects of such changes of circumstances, that they are averse to describe species from garden specimens, unless they are sure that they have been cultivated for a very short period.

'Is not the cultivated wheat' (*Triticum sativum*), asks Lamarck, 'a vegetable brought by man into the state in which we now see it? Let anyone tell me in what country

* Phil. Zool. tom. i. p. 63.

a similar plant grows wild, unless where it has escaped from cultivated fields? Where do we find in nature our cabbages, lettuces, and other culinary vegetables, in the state in which they appear in our gardens? Is it not the same in regard to a great number of animals which domesticity has changed or considerably modified?'* Our domestic fowls and pigeons are unlike any wild birds. Our domestic ducks and geese have lost the faculty of raising themselves into the higher regions of the air, and crossing extensive countries in their flight, like the wild ducks and wild geese from which they were originally derived. A bird which we breed in a cage cannot, when restored to liberty, fly like others of the same species which have been always free. This small alteration of circumstances, however, has only diminished the power of flight, without modifying the form of any part of the wings. But when individuals of the same race are retained in captivity during a considerable length of time, the form even of their parts is gradually made to differ, especially if climate, nourishment and other circumstances be also altered.

The numerous races of dogs which we have produced by domesticity are nowhere to be found in a wild state. In nature we should seek in vain for mastiffs, harriers, spaniels, greyhounds, and other races, between which the differences are sometimes so great that they would be readily admitted as specific between wild animals; 'yet all these have sprung originally from a single race, at first approaching very near to a wolf, if, indeed, the wolf be not the true type which at some period or other was domesticated by man.'

Although important changes in the nature of the places which they inhabit modify the organisation of animals as well as vegetables; yet the former, says Lamarck, require more time to complete a considerable degree of transmutation; and, consequently, we are less sensible of such occurrences. Next to a diversity of the medium in which animals or plants may live, the circumstances which have most influence in modifying their organs are differences in exposure, climate, the nature of the soil, and other local

* Phil. Zool. tom. i. p. 227.

particulars. These circumstances are as varied as are the characters of the species, and, like them, pass by insensible shades into each other, there being every intermediate gradation between the opposite extremes. But each locality remains for a very long time the same, and is altered so slowly that we can only become conscious of the reality of the change by consulting geological monuments, by which we learn that the order of things which now reigns in each place has not always prevailed, and by inference anticipate that it will not always continue the same.*

Every considerable alteration in the local circumstances in which each race of animals exists causes a change in their wants, and these new wants excite them to new actions and habits. These actions require the more frequent employment of some parts before but slightly exercised, and then greater development follows as a consequence of their more frequent use. Other organs no longer in use are impoverished and diminished in size, nay, are sometimes entirely annihilated, while in their place new parts are insensibly produced for the discharge of new functions.†

I must here interrupt the author's argument, by observing, that no positive fact is cited to exemplify the substitution of some *entirely new* sense, faculty, or organ, in the room of some other suppressed as useless. All the instances adduced go only to prove that the dimensions and strength of members and the perfection of certain attributes may, in a long succession of generations, be lessened and enfeebled by disuse; or, on the contrary, be matured and augmented by active exertion; just as we know that the power of scent is feeble in the greyhound, while its swiftness of pace and its acuteness of sight are remarkable—that the harrier and stag-hound, on the contrary, are comparatively slow in their movements, but excel in the sense of smelling.

It was necessary to point out to the reader this important chasm in the chain of evidence, because he might otherwise imagine that I had merely omitted the illustrations for the sake of brevity; but the plain truth is, that there were no

* Phil. Zool. tom. i. p. 232.

† Ibid. p. 234.

examples to be found; and when Lamarck talked 'of the efforts of internal sentiment,' 'the influence of subtle fluids,' and 'acts of organisation,' as causes whereby animals and plants acquire *new organs*, he substituted names for things; and resorted to fictions almost as ideal as the 'plastic virtue' of some geologists of the middle ages.

It is evident that, if some well authenticated facts could have been adduced to establish one complete step in the process of transformation, such as the appearance, in individuals descending from a common stock, of a sense or organ entirely new, and a complete disappearance of some other enjoyed by their progenitors, time alone might then be supposed sufficient to bring about any amount of metamorphosis.*

But to proceed with the system: it being taken for granted, as an undoubted fact, that a change of external circumstances may cause one organ to become entirely obsolete and a new one to be developed, such as never before belonged to the species, the following proposition is announced, which, however startling it may seem, is logically deduced from the assumed premises. It is not the organs, or, in other words, the nature and form of the parts of the body of an animal, which have given rise to its habits and its particular faculties; but, on the contrary, its habits, its manner of living, and those of its progenitors, have in the course of time determined the form of its body, the number and condition of its organs—in short, the faculties which it enjoys. Thus otters, beavers, waterfowl, turtles, and frogs were not made web-footed in order that they might swim; but their wants having attracted them to the water, in search of prey, they stretched out the toes of their feet to strike the water and move rapidly along its surface. By the repeated stretching of their toes, the skin which united them at the base acquired a habit of extension, until, in the course of time, the

* Note, 1872. This perhaps could not be done by Lamarck, nor by any of his successors, on account of the slowness of such changes; but it would have answered the same purpose if any cause or law had been indicated capable of accumulating slight changes continually in one direction and for a special end; and it is for want of this that the theory of Lamarck fell so far short of that of Mr. Darwin, presently to be described.

broad membranes which now connect their extremities were formed.

In like manner, the antelope and the gazelle were not endowed with light agile forms, in order that they might escape by flight from carnivorous animals; but having been exposed to the danger of being devoured by lions, tigers, and other beasts of prey, they were compelled to exert themselves in running with great celerity; a habit which, in the course of many generations, gave rise to the peculiar slenderness of their legs, and the agility and elegance of their forms.

The giraffe was not gifted with a long flexible neck because it was destined to live in the interior of Africa, where the soil was arid and devoid of herbage; but, being reduced by the nature of that country to support itself on the foliage of lofty trees, it contracted a habit of stretching itself up to reach the high boughs, until its neck became so elongated that it could raise its head to the height of 20 feet above the ground.

Another line of argument was then entered upon, in further corroboration of the instability of species. In order, it was said, that individuals should perpetuate themselves unaltered by generation, those belonging to one species ought never to ally themselves to those of another; but such sexual unions do take place, both among plants and animals; and though the offspring of such irregular connections are usually sterile, yet such is not always the case. Hybrids have sometimes proved prolific, where the disparity between the species was not too great; and by this means alone, says Lamarck, varieties may gradually be created by near alliances, which would become races, and in the course of time would constitute what we term species.*

After explaining his reasons for believing in the soundness of the arguments and inferences above set forth, Lamarck next proceeded to enquire what were the original types of form, organisation, and instinct, from which the diversities of character, as now exhibited by animals and plants, were derived? We know, said he, that individuals which are mere varieties of the same species would, if their pedigree

* Phil. Zool. p. 64.

could be traced back far enough, terminate in a single stock; so, according to the same train of reasoning, the species of a genus, and even the genera of a great family, must have had a common point of departure. What, then, was the single stem from which so many varieties of form have ramified? Were there many of these, or are we to refer the origin of the whole animate creation, as the Egyptian priests did that of the universe, to a single egg?

In the absence of any positive data for framing a theory on so obscure a subject, the following considerations were deemed by Lamarck of importance to guide conjecture.

In the first place, if we examine the whole series of known animals, from one extremity to the other, when they are arranged in the order of their natural relations, we find that we may pass progressively, or at least, with very few interruptions, from beings of more simple to those of a more compound structure; and, in proportion as the complexity of their organisation increases, the number and dignity of their faculties increase also. Among plants, a similar approximation to a graduated scale of being is apparent. Secondly, it appears, from geological observations, that plants and animals of more simple organisation existed on the globe before the appearance of those of more compound structure, and the latter was successfully formed at more modern periods; each new race being more fully developed than the most perfect of the preceding era.

Of the truth of the last-mentioned geological theory, Lamarck seems to have been fully persuaded; and he also shows that he was deeply impressed with a belief prevalent amongst the older naturalists, that the primeval ocean invested the whole planet long after it became the habitation of living beings; and thus he was inclined to assert the priority of the types of marine animals to those of the terrestrial, so as to fancy, for example, that the testacea of the ocean existed first, until some of them, by gradual evolution, were *improved* into those inhabiting the land.

These speculative views had already been, in a great degree, anticipated by Demaillet in his Telliamed, and by several other writers who preceded Lamarck; so that the tables were com-

pletely turned on the philosophers of antiquity, with whom it was a received maxim, that created things were always most perfect when they came first from the hands of their Maker; and that there was a tendency to progressive deterioration in sublunary things when left to themselves—

> ——— omnia fatis
> In pejus ruere, ac retrò sublapsa referri.

So deeply was the faith of the ancient schools of philosophy imbued with this doctrine, that, to check this universal proneness to degeneracy, nothing less than the reintervention of the Deity was thought adequate; and it was held, that thereby the order, excellence, and pristine energy of the moral and physical world had been repeatedly restored.

But when the possibility of the indefinite modification of individuals descending from common parents was once assumed, as also the geological inference respecting the progressive development of organic life, it was natural that the ancient dogma should be rejected, or rather reversed, and that the most simple and imperfect forms and faculties should be conceived to have been the originals whence all others were developed. Accordingly, in conformity to these views, inert matter was supposed to have been first endowed with life; until, in the course of ages, sensation was superadded to mere vitality: sight, hearing, and the other senses were afterwards acquired; then instinct and the mental faculties; until, finally, by virtue of the tendency of things to *progressive improvement*, the irrational was developed into the rational.

The reader, however, will immediately perceive that when all the higher orders of plants and animals were thus supposed to be comparatively modern, and to have been derived in a long series of generations from those of more simple conformation, some further hypothesis became indispensable, in order to explain why, after an indefinite lapse of ages, there were still so many beings of the simplest structure. Why have the majority of existing creatures remained stationary throughout this long succession of epochs, while

others have made such prodigious advances? Why are there such multitudes of infusoria and polyps, or of confervæ and other cryptogamic plants? Why, moreover, has the process of development acted with such unequal and irregular force on those classes of beings which have been greatly perfected, so that there are wide chasms in the series; gaps so enormous, that Lamarck fairly admits we can never expect to fill them up by future discoveries?

The following hypothesis was provided to meet these objections. Nature, we are told, is not an intelligence, nor the Deity; but a delegated power—a mere instrument—a piece of mechanism acting by necessity—an order of things constituted by the Supreme Being, and subject to laws which are the expressions of His will. This Nature is *obliged* to proceed gradually in all her operations; she cannot produce animals and plants of all classes at once, but must always begin by the formation of the most simple kinds, and out of them elaborate the more compound, adding to them, successively, different systems of organs, and multiplying more and more their number and energy.

This Nature is daily engaged in the formation of the elementary rudiments of animal and vegetable existence, which correspond to what the ancients termed *spontaneous generation*. She is always beginning anew, day by day, the work of creation, by forming monads, or 'rough draughts' (ébauches), which are the only living things she gives birth to *directly*.*

There are distinct primary rudiments of plants and animals, and *probably* of each of the great divisions of the animal and vegetable kingdoms.† These are gradually developed into the higher and more perfect classes by the slow but unceasing energy of two influential principles: first, *the tendency to progressive advancement* in organisation, accompanied by greater dignity in instinct, intelligence, &c.; secondly, *the force of external circumstances*, or of variations in the physical condition of the earth, or the mutual relations of plants and animals. For, as species spread them-

* Phil. Zool. pp. 65 and 204.

† Animaux sans Vert., tom. i. Introduction, p. 56 note.

selves gradually over the globe, they are exposed from time to time to variations in climate, and to changes in the quantity and quality of their food; they meet with new plants and animals which assist or retard their development by supplying them with nutriment, or destroying their foes. The nature, also, of each locality, is in itself fluctuating; so that, even if the relation of other animals and plants were invariable, the habits and organisation of species would be modified by the influence of local revolutions.

Now, if the first of these principles, *the tendency to progressive development*, were left to exert itself with perfect freedom, it would give rise, says Lamarck, in the course of ages, to a graduated scale of being, where the most insensible transition might be traced from the simplest to the most compound structure, from the humblest to the most exalted degree of intelligence. But, in consequence of the perpetual interference of the *external causes* before mentioned, this regular order is greatly interfered with, and an approximation only to such a state of things is exhibited by the animate creation, the progress of some races being retarded by unfavourable, and that of others accelerated by favourable, combinations of circumstances. Hence, all kinds of anomalies interrupt the continuity of the plan; and chasms, into which whole genera or families might be inserted, are seen to separate the nearest existing portions of the series.

Lamarck's theory of the transformation of the orang-outang into the human species.—Such is the machinery of the Lamarckian system; but the reader will hardly, perhaps, be able to form a perfect conception of so complicated a piece of mechanism, unless it is exhibited in action, so that we may see in what manner it can work out, under the author's guidance, all the extraordinary effects which we behold in the present state of the animate creation. Without attempting to follow the author through the entire process by which, after a countless succession of generations, a small gelatinous body is transformed into an oak or an ape, I shall pass on at once to the last grand step in the progressive scheme, by which the orang-outang, having been evolved out of a monad, is made slowly to attain the attributes and dignity of man.

One of the races of quadrumanous animals which had reached the highest state of perfection, lost, by constraint of circumstances, the habit of climbing trees, and of hanging on by grasping the boughs with their feet as with hands. The individuals of this race being obliged, for a long series of generations, to use their feet exclusively for walking, and ceasing to employ their hands as feet, were transformed into bimanous animals, and what before were thumbs became mere toes, no separation being required when their feet were used solely for walking. Having acquired a habit of holding themselves upright, their legs and feet assumed, insensibly, a conformation fitted to support them in an erect attitude, till at last these animals could no longer go on all-fours without much inconvenience.

The Angola orang (*Simia troglodytes*, Linn.) is the most perfect of animals; much more so than the Indian orang (*Simia Satyrus*), which has been called the orang-outang, although *both* are *very inferior* to man in corporeal powers and intelligence. These animals frequently hold themselves upright; but their organisation has *not yet* been sufficiently modified to sustain them habitually in this attitude, so that the standing posture is very uneasy to them. When the Indian orang is compelled to take flight from pressing danger, he immediately falls down upon all-fours, showing clearly that this was the original position of the animal. Even in man, whose organisation, in the course of a long series of generations, has advanced so much farther, the upright posture is fatiguing, and can be supported only for a limited time, and by aid of the contraction of many muscles. If the vertebral column formed the axis of the human body, and supported the head and all the other parts in equilibrium, then might the upright position be a state of repose; but, as the human head does not articulate in the centre of gravity, as the chest, belly, and other parts press almost entirely forward with their whole weight, and as the vertebral column reposes upon an oblique base, a watchful activity is required to prevent the body from falling.* Children who have large heads and prominent bellies can hardly walk at

* Phil. Zool. p. 353.

the end even of two years; and their frequent tumbles indicate the natural tendency in man to resume the quadrupedal state.*

Now, when so much progress had been made by the quadrumanous animals before mentioned, that they could hold themselves habitually in an erect attitude, and were accustomed to a wide range of vision, and ceased to use their jaws for fighting and tearing, or for clipping herbs for food, their snout became gradually shorter, their incisor teeth became vertical, and the facial angle grew more open.

Among other ideas which the natural *tendency to perfection* engendered, the desire of ruling suggested itself, and this race succeeded at length in getting the better of the other animals, and made themselves masters of all those spots on the surface of the globe which best suited them. They drove out the animals which approached nearest them in organisation and intelligence, and which were in a condition to dispute with them the good things of this world, forcing them to take refuge in deserts, woods, and wildernesses, where their multiplication was checked, and the progressive development of their faculties retarded; while, in the meantime, the dominant race spread itself in every direction, and lived in large companies, where new wants were successively created, exciting them to industry, and gradually perfecting their means and faculties.

In the supremacy and increased intelligence acquired by the ruling race, we see an illustration of the natural tendency of the organic world to grow more perfect; and, in their influence in repressing the advance of others, an example of one of those disturbing causes before enumerated, that *force of external circumstances* which causes such wide chasms in the regular series of animated being.

When the individuals of the dominant race became very numerous, their ideas greatly increased in number, and they felt the necessity of communicating them to each other, and of augmenting and varying the signs proper for the communication of ideas. Meanwhile the inferior quadrumanous animals, although most of them were gregarious, acquired

* Phil. Zool. p. 354.

no new ideas, being persecuted and restless in the deserts, and obliged to fly and conceal themselves, so that they conceived no new wants. Such ideas as they already had remained unaltered, and they could dispense with the communication of the greater part of these. To make themselves, therefore, understood by their fellows, required merely a few movements of the body or limbs—whistling, and the uttering of certain cries varied by the inflexions of the voice.

On the contrary, the individuals of the ascendant race, animated with a desire of interchanging their ideas, which became more and more numerous, were prompted to multiply the means of communication, and were no longer satisfied with mere pantomimic signs, nor even with all the possible inflexions of the voice, but made continual efforts to acquire the power of uttering articulate sounds, employing a few at first, but afterwards varying and perfecting them according to the increase of their wants. The habitual exercise of their throat, tongue, and lips, insensibly modified the conformation of these organs, until they became fitted for the faculty of speech.*

In effecting this mighty change, 'the exigencies of the individuals were the sole agents; they gave rise to efforts, and the organs proper for articulating sounds were developed by their habitual employment.' Hence, in this peculiar race, the origin of the admirable faculty of speech; hence also the diversity of languages, since the distance of places where the individuals composing the race established themselves soon favoured the corruption of conventional signs.†

In conclusion, it may be proper to observe that the above sketch of the Lamarckian theory is no exaggerated picture, and those passages which have probably excited the greatest surprise in the mind of the reader are literal translations from the original.

* Lamarck's Phil. Zool. tom. i. p. 356. † Ibid. p. 357.

CHAPTER XXXV.

THEORIES AS TO THE NATURE OF SPECIES, AND DARWIN ON NATURAL SELECTION.

OBJECTIONS URGED AGAINST THE THEORY OF TRANSMUTATION AND LAMARCK'S REPLIES—MUMMIES OF ANIMALS AND SEEDS OF PLANTS FROM EGYPTIAN TOMBS IDENTICAL IN CHARACTER WITH SPECIES NOW LIVING—LINNÆUS' OPINION THAT SPECIES HAVE BEEN CONSTANT SINCE THEIR CREATION—BROCCHI'S HYPOTHESIS OF THE GRADUAL DIMINUTION OF VITAL POWER IN A SPECIES—WHETHER IF NEW SPECIES ARE CREATED FROM TIME TO TIME THEIR FIRST APPEARANCE MUST HAVE BEEN WITNESSED BY THE NATURALIST—GEOFFROY ST. HILAIRE AND LAMARCK ON RUDIMENTARY ORGANS—THE QUESTION OF SPECIES AS TREATED OF IN THE 'VESTIGES OF CREATION'—MR. ALFRED WALLACE ON THE LAW WHICH HAS REGULATED THE INTRODUCTION OF NEW SPECIES—MR. DARWIN ON NATURAL SELECTION AND MR. WALLACE ON THE SAME—DARWIN'S ORIGIN OF SPECIES AND THE CHANGE OF OPINION WHICH IT EFFECTED—DR. HOOKER'S FLORA OF AUSTRALIA AND HIS VIEWS AS TO THE ORIGIN OF SPECIES BY VARIATION.

Objections urged against the Theory of Transmutation and Lamarck's Replies.—The theory of the transmutation of species, considered in the last chapter, was received with some degree of favour by many naturalists, from their desire to dispense, as far as possible, with the repeated intervention of a First Cause, as often as geological monuments attest the successive appearance of new races of animals and plants, and the extinction of those pre-existing. But, independently of a predisposition to account, if possible, for a series of changes in the organic world by the regular action of secondary causes, we have seen that in truth many perplexing difficulties present themselves to all who attempt to establish the reality and constancy of the specific character. And if once there appears ground for reasonable doubt, in regard to the constancy of species, the amount of transformation which they are capable of undergoing might seem to resolve itself into a mere question of the quantity of time

assigned to the past and future duration of animate existence.

The opponents of Lamarck objected to his arguments that he could not adduce a single instance of the gradual conversion of any one species of animal or plant into another; and that in his appeal to the results obtained by the breeder and horticulturist, he had failed to show such a change in the structure and constitution of individuals descending from a common stock as might fairly entitle the new race to rank as a distinct species. It was conceded, for example, on all hands that the modifications produced in the different races of dogs exhibit the influence of man in the most striking point of view. These animals had been transported into every climate, and placed in every variety of circumstances: they had been made, as M. Dureau de la Malle observed, the servant, the companion, the guardian, and the intimate friend of man, and the power of a superior genius had had a wonderful influence not only on their forms, but on their manners and intelligence.* Different races have undergone remarkable changes in the quantity and colour of their clothing; the dogs of Guinea are almost naked, while those of the Arctic Circle are covered with a warm coat both of hair and wool, which enables them to bear the most intense cold without inconvenience. There are differences also of another kind no less remarkable, as in size, the length of their muzzles, and the convexity of their foreheads. 'The difference in stature,' said Cuvier, 'in some canine races as compared to others is as 1 to 5 in linear dimensions,' making a difference of a hundredfold in volume.†

But, said the advocates of the immutability of species, if we look for some essential changes, such as might serve as a foundation for the theory of Lamarck, respecting the growth of new organs and the gradual obliteration of others, we find nothing of the kind. In all the varieties of the dog, as Cuvier affirmed, the relation of the bones with each other remains essentially the same; the form of the teeth never changes in any perceptible degree, except that, in some

* Dureau de la Malle, Ann. des Sci. Nat., tom. xxi. p. 53, Sept. 1830.

† Cuvier, Discours Prélimin. p. 128.

individuals, one additional false grinder occasionally appears, sometimes on the one side, and sometimes on the other.* The greatest departure from a common type—and it constitutes the maximum of variation as yet known in the animal kingdom—is exemplified in those races of dogs which have a supernumerary toe on the hind foot with the corresponding tarsal bones; a variety analogous to one presented by six-fingered families of the human race.†

It was moreover urged, and of all objections this was the most serious, that however distinct were the various races of the dog, they could all breed freely together and produce fertile offspring, as was also the case with various domesticated birds, such as the common fowl, of which such marked varieties had been obtained. In no instance had the mongrel offspring been shown to be habitually sterile, like the common mule or the offspring of the horse and ass, where the two parents belong to two undoubtedly distinct species.

When the controversy had been brought to this point, and the amount of possible variation of animals under domestication, and of plants under culture, was still under discussion, the followers of Lamarck sometimes lamented that no accurate descriptions, and figures of known species, had been handed down from the earliest periods of history, such as might have afforded data for comparing the condition of the same species, at two periods considerably remote. To this, however, the opponents of transmutation replied, that we are in a great measure independent of such evidence, since, by a singular accident, the priests of Egypt have bequeathed to us, in their cemeteries, that information which the museums and works of the Greek and Roman philosophers have failed to transmit.

It had fortunately happened that the men of science who accompanied the French armies during their four years' occupation of Egypt, from 1797 to 1801, instead of employing their whole time, as so many preceding investigators had done, in exclusively collecting human mummies, had examined diligently and sent home great numbers of embalmed bodies of consecrated animals, such as the bull, the dog,

* Disc. Prél. p. 129, sixth edition. † Ibid.

the cat, the ape, the ichneumon, the crocodile, and the ibis.

They who have never raised their conceptions of the import of Natural History beyond the admiration of beautiful objects or the exertion of skill in detecting specific differences, would wonder at the enthusiasm expressed in Paris at the beginning of this century, amidst the din of arms and the stirring excitement of political events, in regard to these precious remains. In the official report, drawn up by the Professors of the Museum at Paris, on the value of the objects alluded to, the following passages might seem extravagant, unless we reflect how fully the reporters (Cuvier, Lacépède, and Lamarck) appreciated the bearing of the facts thus brought to light on the past history of the globe.

'It seems,' say they, 'as if the superstition of the ancient Egyptians had been inspired by Nature, with a view of transmitting to after ages a monument of her history. That extraordinary and eccentric people, by embalming with so much care the brutes which were the objects of their stupid adoration, have left us, in their sacred grottos, cabinets of zoology almost complete. The climate has conspired with the art of embalming to preserve the bodies from corruption, and we can now assure ourselves by our own eyes what was the state of a great number of species three thousand years ago. We can scarcely restrain the transports of our imagination, on beholding thus preserved, with their minutest bones, with the smallest portions of their skin, and in every particular most perfectly recognisable, many an animal, which at Thebes or Memphis, 2,000 or 3,000 years ago, had its own priests and altars.' *

Among the Egyptian mummies thus procured were not only those of numerous wild quadrupeds, birds, and reptiles; but, what was perhaps of still higher importance in helping to decide the great question under discussion, there were the mummies of domestic animals, among which those above mentioned, the bull, the dog, and the cat, were frequent. Now, such was the conformity, says Cuvier, of the whole of these species and races to those now living, that there was

* Ann. du Muséum d'Hist. Nat. tom. i. p. 234. 1802.

no more difference between them than between the human mummies and the embalmed bodies of men of the present day. Yet some of these animals have since that period been transported by man to almost every variety of climate, and forced to accommodate their habits to new circumstances as far as their nature would permit. The cat, for example, has been carried over the whole earth, and, within the last three centuries, has been naturalised in every part of the New World—from the cold regions of Canada to the tropical plains of Guiana; yet it has scarcely undergone any perceptible mutation, and is still the same animal which was held sacred by the Egyptians. Of the ox, undoubtedly, there are many very distinct races; but the bull Apis, which was led in solemn processions by the Egyptian priests, did not differ from some of those now living.

Nor was the evidence derived from the Egyptian monuments confined to the animal kingdom; the fruits, seeds, and other portions of twenty different plants, were faithfully preserved in the same manner; and among these the common wheat was procured by Delille, from closed vessels in the sepulchres of the kings, the grains of which retained not only their form, but even their colour; so effectual had proved the process of embalming with bitumen in a dry and equable climate. No difference could be detected between this wheat and that which now grows in the East and elsewhere, and similar identifications were made in regard to many other plants.

In answer to the argument drawn from this class of facts Lamarck observed, that 'the animals and plants referred to had not experienced any modification in their specific characters, because the climate, soil, and other conditions of life had not varied in the interval. But if,' he went on to say, 'the physical geography, temperature, and other natural conditions of Egypt had altered as much as we know they have done in many countries in the course of geological periods, the same animals and plants would have deviated from their pristine types so widely as to rank as new and distinct species.' * This reply, when we consider its date (about the year 1809),

* Phil. Zool. pp. 70–71.

may well lay claim to our admiration, as it evinced Lamarck's thorough conviction, that geological changes are brought about so slowly that the lapse of thirty or forty centuries is utterly insignificant in the history of a species. Nearly all the men of science of his day, even the great majority of geologists, entertained extremely narrow views in regard to the duration of those periods of the past of which they were studying the archives. They were generally inclined to attribute all great changes of the earth's crust, and its inhabitants, to brief and violent catastrophes, against which Lamarck emphatically protested.* Yet neither he nor any of his contemporaries could as yet form any conception of the number and real magnitude of the revolutions in the animate world with which paleontology has since made us familiar. In certain passages of his work he admitted that possibly the Paleotherium, Anoplotherium, and some other fossil genera of quadrupeds then recently described by Cuvier as occurring in tertiary strata near Paris, may have disappeared, having, perhaps, been exterminated by the power of man. But in regard to smaller animals, especially those of the aquatic tribes, which could not have been the victims of human intervention, he sometimes expressed a doubt whether most of these may not still have their representatives surviving in regions unexplored by the naturalist. Being aware, however, that the specific and generic forms of animals and plants preserved in the rocks are more unlike those now existing in proportion as they are more ancient, Lamarck expressed his belief that in those cases where the fossil animals can be identified with the living, the strata containing them must be very modern, their descendants not having had time to vary, except within extremely narrow limits.†

It was by this constant reference to time as an essential element even in the definition of a species, that the teaching of Lamarck differed from that of Linnæus, Blumenbach, and Cuvier.

Linnæus on species.—Linnæus in one of his treatises had

* Phil. Zool. p. 80.

† Ibid. chap. iii., De l'Espèce, p. 79.

said that classes and orders are the inventions of science, but species are the work of nature.* In another place he went so far as to declare that genera, like species, are primordial creations.†

Expressions may doubtless be found in some of his speculative essays, implying that he thought that some species at least were the daughters of time, '*temporis filiæ*,' and we shall see in Chap. XXXVII. that when a great number of closely allied species existed in the same region, he strongly suspected that they might be derived from other species—possibly that they were hybrids, and had become so far permanent as to require to be treated as distinct species. But his deliberate opinion was contained in the following aphorism: 'We reckon just so many species as there were forms created in the beginning.' ‡ Blumenbach declared that 'no general rule can be laid down for determining the distinctness of species, as there is no particular class of characters which can serve as a criterion. In each case we must be guided by *analogy* and *probability*.'

In former editions of this work from 1832 to 1853, I did not venture to differ from the opinion of Linnæus, that each species had remained from its origin such as we now see it, being variable, but only within certain fixed limits. The mystery in which the origin of each species was involved seemed to me no greater than that in which the beginning of all vital phenomena on the earth is shrouded. But I undertook to show that the gradual extinction of species one after another was part of the constant and regular course of nature, and must have been so throughout all geological time, because the climate, and the position of land and sea, and all the principal conditions of the organic and inorganic world, are always, and have been always, undergoing change. I pointed out how the struggle for existence among species, and the increase and spread of some of them, must tend to the extermination of others; and as these would disappear gradually and singly from the scene, I suggested

* 'Classis et Ordo est sapientiæ, Species naturæ opus.'

† 'Genus omne est naturale, in primordio tale creatum,' &c. Phil. Bot. § 159. See also ibid. § 162.

‡ 'Totidem numeramus species quot in principio formæ sunt creatæ.'

that probably the coming in of new species would in like manner be successive, and that there was no geological sanction for the favourite doctrine of some theorists, that large assemblages of new forms had been ushered in at once to compensate for the sudden removal of many others from the scene.

Brocchi on the dying out of a species.—An Italian geologist, Brocchi, the author in 1814 of an able work on the fossil shells of the sub-Apennine Hills, endeavoured to imagine some regular and constant law by which species might be made to disappear from the earth gradually and in succession. The death, he suggested, of a species might depend, like that of individuals, on certain peculiarities of constitution conferred upon them at their birth; and as the longevity of the one depends on a certain force of vitality, which, after a period, grows weaker and weaker, so the duration of the other may be governed by the quantity of prolific power bestowed upon the species which, after a season, may decline in energy, so that the fecundity and multiplication of individuals may be gradually lessened from century to century, 'until that fatal term arrives when the embryo, incapable of extending and developing itself, abandons, almost at the instant of its formation, the slender principle of life by which it was scarcely animated,—and so all dies with it.'* In opposition to this doctrine, I contended that there is no reason to suspect that the last individuals of a species of which the numbers are diminishing are physiologically deteriorated, or are in the least degree impaired in their prolific powers; for there are known causes in the animate and inanimate world which must in the course of ages annihilate species, however vigorous their powers of reproduction might remain. As the death of the last representatives of a species would be abrupt, I conjectured that the birth of new forms might be equally so, but as I had entire faith in the doctrine that what is now going on in the natural world affords a true indication of what has been and will be, I assumed that the coming in of new species must be going on at about the same rate as the dying out of old ones; and I

* Brocchi, Conch. Foss. Subap. tome i. 1814.

therefore felt myself called upon to explain how the birth of new species could be always in progress, and yet the botanist and zoologist remain wholly unconscious of the occurrence of events so wonderful, and to them of such transcendent interest.

Assuming that species were specially created from time to time to fill up the gaps to which the never-ceasing changes of the animate and inanimate world must give rise, I enquired what kind of evidence we had a right to expect of the origin of new forms of animals and plants in the course of the last twenty or thirty centuries. Ought we to have been as conscious of the fact as we are of the lessening of the numbers and the occasional extermination of particular species? It was obviously, I remarked, more easy to prove that a species, once numerously represented in a given district, had ceased to be, than that some other which did not pre-exist had made its appearance—assuming always that single stocks only of each animal and plant are originally created, and that individuals of new species do not suddenly start up in many different places at once. The latter hypothesis had already been considered by Linnæus, and pronounced by him to be unphilosophical because quite unnecessary, since, as he observed, every animal or plant, even those which increase slowly, are capable in twenty or thirty generations of stocking a large part of the whole globe with their descendants.

So imperfect has the science of Natural History remained down to our own times, that, within the memory of persons now living, the numbers of known animals and plants have been doubled, or even quadrupled, in many classes. New and often conspicuous species are annually discovered in parts of the old continent, long inhabited by the most civilised nations. Conscious, therefore, of the limited extent of our information, we always infer, when such discoveries are made, that the beings in question had previously eluded our research; or had at least existed elsewhere, and only migrated at a recent period into the territories where we now find them. It is difficult to look forward to the time when we shall be entitled to make any other hypothesis in regard

to all the marine tribes, and to by far the greater number of the terrestrial; such as birds, and insects, and a large proportion of plants, especially those of the cryptogamous class, many of which possess such unlimited powers of diffusion as to be almost cosmopolitan in their range.

It may perhaps be said that if new species were suddenly called into being by special acts of creation, some forest tree or new quadruped ought to have been seen, for the first time, within the last ten or twenty centuries in the more populous parts of such countries as England or France. In that case, the naturalist might have been able to demonstrate that no similar living form had before existed in the district.

Now, although this argument may seem plausible, its force will be found to depend entirely on the rate of fluctuation which we suppose to prevail in the animate world, and on the proportion which such conspicuous subjects of the animal and vegetable kingdoms bears to those which are less known and escape our notice. There are perhaps more than a million species of plants and animals, exclusive of the microscopic and infusorial animalcules, now inhabiting the terraqueous globe; so that if only one of these were to become extinct annually, and one new one were to be every year called into being, much more than a million of years might be required to bring about a complete revolution in organic life.

I have never ventured to hazard any precise hypothesis as to the probable rate of change; but none will deny that when the *annual* birth and the *annual* death of one species on the globe was proposed as a mere speculation, this at least was to imagine no slight degree of instability in the animate creation. If we divide the surface of the earth into twenty regions of equal area, one of these might comprehend a space of land and water about equal in dimensions to Europe, and might contain a twentieth part of the million of species which may be assumed to exist in the animal kingdom. In this region one species only would, according to the rate of mortality before assumed, perish in twenty years, or only five out of fifty thousand in the course of a century.

But as a considerable proportion of the whole would belong to the aquatic classes, with which we have a very imperfect acquaintance, we must exclude them from our consideration; and if they constitute half of the entire number, then one species only might be lost in forty years among the terrestrial tribes. Now the Mammalia, whether terrestrial or aquatic, bear so small a proportion to other classes of animals, forming less, perhaps, than one thousandth part of the whole, that if the longevity of species in the different orders were equal, a vast period must elapse before it would come to the turn of this conspicuous class to lose one of their number. If one species only of the whole animal kingdom died out in forty years, no more than one mammifer might disappear in 40,000 years in a region of the dimensions of Europe.

It is easy, therefore, to see, that in a small portion of such an area, in countries, for example, of the size of England and France, periods of much greater duration must elapse before it would be possible to authenticate the first appearance of one of the larger plants and animals, assuming the annual birth and death of one species to be the rate of vicissitude in the animate creation throughout the world. It would follow from the above considerations that if Lamarck was entitled to plead insufficiency of time when challenged to bring forward a single case of transmutation, the advocates of special creation were equally entitled to say that, if the introduction of new species goes on as slowly as the extinction of old ones, it could not be expected that they should have witnessed the first starting into being of a new animal or plant.

Geoffroy St. Hilaire and Lamarck on rudimentary organs.— The great majority of the best naturalists and geologists who succeeded Lamarck were content to believe with Humboldt that the origin of species was one of those mysteries which it was not given to natural science to penetrate. Omalius d'Halloy, however, in his 'Elements of Geology,' which he published in 1831, and in six subsequent editions, taught that the species of animals now living were the descendants of progenitors which have left their fossil remains in the later Tertiary formations. I asked him in the year 1867, when

he was in his eighty-fourth year, by what facts and reasonings he had been led to entertain this view, and he told me that he owed his convictions on this head to the lectures of Geoffroy St. Hilaire, to which he had listened in the early part of this century at Paris. That great zoologist, he said, never lost an opportunity, when he spoke of the rudimentary organs found in so many animals, of pointing out their bearing on the theory of transmutation. According to him they were clearly the relics of parts which had been serviceable in some remote ancestor and had been reduced in size by disuse, and he rejected the idea as puerile that useless organs had been created for the sake of uniformity of plan.

I may here remark that in my brief abstract of Lamarck's theory drawn up by me originally in 1832, and which for reasons explained in the last chapter (p. 248, note) I have now reprinted without alteration or addition, I omitted, when referring to what he had said on the impoverishment and final disappearance of organs by disuse, to cite many examples which he gives in the 'Philosophie Zoologique' in illustration of this principle. Among other facts the abortive teeth concealed in the jaws of some mammalia are mentioned, such teeth not being required because their food is swallowed without mastication. The discovery also by G. St. Hilaire of teeth in the fœtus of a whale is alluded to, and the small size of the eyes in the mole, which makes scarcely any use of its organs of vision. Allusion is also made to the aquatic reptile called *Proteus anguinus*, inhabiting the waters of dark subterranean caverns, which retains only the vestiges or rudiments of eyes.*

The question of species as treated in the 'Vestiges of Creation.'—But, speaking generally, it may be said that all the most influential teachers of geology, paleontology, zoology, and botany continued till near the middle of this century either to assume the independent creation and immutability of species, or carefully to avoid expressing any opinion on this important subject. In England the calm was first broken by the appearance in 1844 of a work entitled 'The Vestiges of Creation,' in which the anonymous author had gathered

* Phil. Zool. tom. i. p. 240, where other examples are also given.

together and presented to the public, with great clearness and skill, the new facts brought to light in geology and the kindred sciences since the time of Lamarck in favour of the transmutation of species and their progressive development in time. He availed himself of the generalisations of paleontologists on the changes observable in the fossil fauna and flora of successive epochs of the past, showing that the structural affinity was greatest in those which stood nearest each other in position when the strata were arranged in chronological order, and that there had been a gradual approximation of the animate world as it changed from period to period to the state of things now represented by the living creation.

The embryological investigations of Tiedemann and others were referred to as being in harmony with the doctrine of transmutation; the various phases of development through which a mammifer passes when in the fœtal state representing in succession the likeness of a fish, reptile and bird, and lastly putting on the characters proper to the highest class of vertebrata. It was also suggested that these metamorphoses were comparable to the creative additions made in like chronological order to the organic world of past ages as revealed to us by the fossil remains preserved in the rocks. The arguments which Lamarck and others had derived from rudimentary organs in favour of their views were re-stated and their validity emphatically insisted upon. The unity of plan exhibited by the whole organic creation, fossil and recent, and the mutual affinities of all the different classes of the animal and vegetable kingdoms, were declared to be in harmony with the idea of new forms having proceeded from older ones by generation, species having been gradually modified by the influence of external conditions.

Lamarck had rendered his hypothesis very complete by embracing without any essential change the notions of Aristotle as to spontaneous generation. The simplest rudiments or germs of life were assumed to be always coming into being. This would account for the present abundance of species of the lowest grades of animal and vegetable existence in spite of the constant advance throughout past time of the

organic creation towards a more perfect state. In his eagerness to supply the evidence which was wanting to confirm the reality of the working of this part of the plan of nature, the author of the 'Vestiges' displayed an extraordinary want of philosophical caution. For he cited experiments which were supposed to prove that the action of a voltaic pile on a solution of potash could give origin to new species of insects. The careless way in which these experiments had been conducted contrasted in a striking manner with the extreme caution displayed by those who had been endeavouring to test the truth or falsehood of Harvey's dictum that 'every living thing comes from an egg.' The result of every increase in the power of the microscope had been to refute the theory of spontaneous generation, or at least to force the abettors of the old doctrine to take refuge in the obscure region of the infinitely minute. Distrust of the soundness of the author's judgment was also engendered by a suspicion that he was not practically versed in the study of any one department of natural knowledge. Every weak point, moreover, in this treatise was exposed with unsparing severity by critics who were impatient of the popularity it enjoyed, notwithstanding the adoption by the author of Lamarck's doctrine that Man was not only the last link of a long series of progressive developments, but had been connected by descent with the inferior animals.

Darwin and Wallace on the origin of species.—The next important effort to determine the manner in which new species may have originated was made in 1855 by Mr. Alfred Wallace in the 'Annals of Natural History,'* in an essay entitled 'On the Law which has regulated the Introduction of New Species.' The opinions enounced in this paper carried with them the authority of one who was well versed in several departments of natural history, especially ornithology and entomology. He had first explored during four years, conjointly with Mr. H. W. Bates, the valley of the river Amazons, and the neighbouring equatorial parts of South America, their expedition having been

* Series 2, vol. xvi. Republished in 'Contributions to the Theory of Natural Selection,' p. 1.

expressly undertaken to collect facts 'towards solving the problem of the origin of species.'* Mr. Wallace had afterwards spent many years in studying the zoology of the Malay Archipelago, devoting his attention especially to the birds and insects; and the result of his experience, aided by the information obtained from geological writers, was summed up in the following proposition, 'that every species has come into existence coincident both in space and time with a pre-existing closely allied species.'† Mr. Darwin,‡ when referring subsequently to this paper in his 'Origin of Species,' has stated that he knew from correspondence with Mr. Wallace that the cause to which he attributed the coincidence here alluded to was no other than 'generation with modification,' or, in other words, the 'closely allied antitype' was the parent stock from which the new form had been derived by variation. All the most telling arguments which Lamarck had brought forward, and those drawn from various sources which the 'Vestiges' had superadded, in favour of species being the result of indefinite modification, instead of special creation, were briefly and ably summed up by Mr. Wallace; but it was clear that the evidence which had most powerfully influenced his mind, was that derived from his own experience of the geographical distribution of species, and especially of birds and insects.

In geography, he remarked, a genus or species rarely occurs in two very distant localities without being also found in the intermediate space; so in geology the life of a genus or species is not interrupted, no species having come into existence twice, or having been renewed after having once died out. For the manner in which the gradual extinction of species had been brought about and was still in progress, Mr. Wallace referred to my chapter on that subject in the 'Principles of Geology,' confining his speculations to the manner in which new forms were introduced from time to time to replace those which were lost.

Meanwhile Mr. Charles Darwin, well known by his 'Voyage in the Beagle,' and various works on Geology, had been for

* Bates' Preface to his 'Naturalist on the River Amazons.'

† Annals of Nat. Hist. ser. 2, vol. xvi. p. 186.

‡ 1st ed. p. 355; 4th ed. p. 424.

many years busily engaged in collecting materials for a great work on the origin of species; having made for that purpose a vast series of original observations and experiments on domesticated animals and cultivated plants, and having reflected profoundly on those problems in geology and biology which were calculated to throw most light on that question. For eighteen years these researches had all been pointing to the same conclusion, namely, that the species now living had been derived by variation and generation from those which had pre-existed, and these again from others of still older date. Several of his MS. volumes on this subject had been read by Dr. Hooker as long ago as 1844, and how long the ever-accumulating store of facts and reasonings might have remained unknown to the general public, had no one else attempted to work out the same problem, it is impossible to say. But at length Mr. Darwin received a communication, dated February 1858, from Mr. Wallace, then residing at Ternate in the Malay Archipelago, entitled 'On the Tendency of Varieties to depart indefinitely from the Original Type.'

The Author requested Mr. Darwin to show this essay to me should he think it sufficiently novel and interesting. It was brought to me by Dr. Hooker, who remarked how complete was the coincidence of Mr. Wallace's new views and those contained in one of the chapters of Mr. Darwin's unpublished work. Accordingly, he suggested that it would be unfair to let Mr. Wallace's essay go to press unaccompanied by the older memoir on the same subject. Although, therefore, Mr. Darwin was willing to waive his claim to priority, the two papers were read on the same evening to the Linnæan Society and published in their Proceedings for 1858. The title of the chapter extracted from Mr. Darwin's MS. ran as follows: 'On the Tendency of Species to form Varieties, and on the Perpetuation of Species and Varieties by Natural Means of Selection.'

Already in the previous year, September 1857, Mr. Darwin had sent to Professor Asa Gray, the celebrated American botanist, a brief sketch of his forthcoming treatise on what he then termed 'Natural Selection.' This letter, also printed by the Linnæan Society together with the papers above alluded

to, contained an outline of the leading features of his theory of selection as since explained, showing how new races were formed by the breeder, and how analogous results might or must occur in nature under changed conditions in the animate and inanimate world. Reference was made in the same letter to the law of human population first enunciated by Malthus, or the tendency in man to increase in a geometrical ratio, while the means of subsistence cannot be made to augment in the same ratio. We were reminded that in some countries the human population has doubled in twenty-five years, and would have multiplied faster if food could have been supplied. In like manner every animal and plant is capable of increasing so rapidly, that if it were unchecked by other species, it would soon occupy the greater part of the habitable globe; but in the general struggle for life few only of those which are born into the world can obtain subsistence and arrive at maturity. In any given species those alone survive which have some advantage over others, and this is often determined by a slight peculiarity capable in a severe competition of turning the scale in their favour. Notwithstanding the resemblance to each other and to their parents of all the individuals of the same family, no two of them are exactly alike. The breeder chooses out from among the varieties presented to him those best suited to his purpose, and the divergence from the original stock is more and more increased by breeding in each successive generation from individuals which possess the desired characters in the most marked degree. In this manner Mr. Darwin suggests that as the surrounding conditions in the organic and inorganic world slowly alter in the course of geological periods, new races which are more in harmony with the altered state of things must be formed in a state of nature, and must often supplant the parent type.

Although this law of natural selection constituted one only of the grounds on which Mr. Darwin relied for establishing his views as to the origin of species by variation, yet it formed so original and prominent a part of his theory that the fact of Mr. Wallace having independently thought out the same principle and illustrated it by singularly analogous

examples, is remarkable. It raises at the same time a strong presumption in favour of the truth of the doctrine. Both writers referred to the number of the feathered tribe which perish annually. 'Very few birds,' says Mr. Wallace, 'produce less than two young ones each year, while many have six, eight, or ten; and if we suppose that each pair produce young only four times in their life, each would at this rate increase in fifteen years to nearly ten millions, whereas we have no reason to believe that the number of the birds of any country increases at all in fifteen or even in 150 years. It is evident, therefore, that each year an immense number of birds must perish, as many in fact as are born; and as on the lowest calculation the progeny are each year twice as numerous as their parents, it follows that whatever be the average number of individuals existing in any given country, twice that number must perish annually.

'Large broods are superfluous: on the average all above one become food for hawks and kites, wild cats and weazels, or perish of cold and hunger as winter comes on.'* The most remarkable instance of an immense bird population is that of the passenger pigeon of the United States, 'which lays only one or at most two eggs, and is said to rear generally but one young one. Why is this bird so extraordinarily abundant, while others producing two or three times as many young are much less plentiful? The explanation is not difficult. The food most congenial to this species, and on which it thrives best, is abundantly distributed over a very extensive region, offering such differences of soil and climate, that in one part or another of the area the supply never fails. The bird is capable of very rapid and long continued flight, so that it can pass without fatigue over the whole of the district it inhabits, and as soon as the supply of food begins to fail in one place is able to discover a fresh feeding-ground. This example strikingly shows us that the procuring a constant supply of wholesome food is almost the sole condition requisite for ensuring the rapid increase of a given species, since neither the limited fecundity, nor the unrestrained

* Journ. of Linnæan Soc., vol. iii. p. 55. 1858. 'Contributions to Natural Selection,' p. 30.

attacks of birds of prey and of man, are here sufficient to check it.'*

When pointing out how every variation from the typical form of a species gives an advantage to some individuals over others, Mr. Wallace shows that even a change of colour, by rendering certain animals more or less distinguishable, affects their safety. He also observes that in a state of nature, a race better fitted for changed conditions would never revert to the form which it had displaced; although in the case of domesticated animals allowed to run wild or become 'feral,' they must, to a certain extent, recover the character which they had lost during their subjugation to man, for reasons which will be explained in Chapter XXXVII. The essay concluded with some judicious criticisms on Lamarck's notion that animals may by their own efforts promote the development of some of their organs, or even acquire new ones. 'Changes,' says Mr. Wallace, 'have been brought about, not by the volition of the creatures themselves, but by the survival of varieties which had the greatest facilities of obtaining food. The giraffe did not acquire its long neck by desiring to reach the foliage of lofty trees and by constantly stretching out its neck for that purpose, but varieties which occurred with a longer neck than usual had an advantage over their shorter-necked companions, and, on the first scarcity of food, were enabled to survive them.'†

After the publication of the detached chapter of his book in the Linnæan Proceedings, Mr. Darwin was persuaded by his friends that he ought no longer to withhold from the world the result of his investigations on the nature and origin of species, and his theory of Natural Selection. Great was the sensation produced in the scientific world by the appearance of the abridged and condensed statement of his views comprised in his work entitled 'On the Origin of Species by means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life.' From the hour of its appearance it gave, as Professor Huxley truly said, 'a

* Journ. of Linnæan Soc., vol. iii. p. 55. 1858. 'Contributions to Natural Selection,' p. 42.

† Journ. of Linnæan Soc., p. 61, 'Contributions to Natural Selection,' p. 42.

new direction to biological speculation,' for even where it failed to make proselytes, it gave a shock to old and time-honoured opinions from which they have never since recovered. It effected this not merely by the manner in which it explained how new races and species might be formed by Natural Selection, but also by showing that, if we assume this principle, much light is thrown on many very distinct and otherwise unconnected classes of phenomena, both in the present condition and past history of the organic world.

Hooker on variation and selection and the formation of species in the vegetable world.—The abandonment of the old received doctrine of the 'immutability of species' was accelerated in England by the appearance, in the same year (1859), of Dr. Hooker's essay on the Flora of Australia. In several of his previous writings this eminent botanist had said all that could be said in support of the 'constancy of the specific character in the vegetable world.' He had been freely discussing for fifteen years with Mr. Darwin all the facts and arguments which they could bring to bear on this question, but he stated in his Introduction, that until the views of his friend and those of Mr. Wallace in favour of Natural Selection had been made known, he scarcely felt himself at liberty frankly to declare how far, as a botanist, he was prepared to go in the same direction. He had been occupied for more than twenty years in the study of plants of various parts of the world, arctic, temperate, and tropical, insular and continental. He had personally explored the floras of several of these regions, had described and classified thousands of species, and was well known to unite caution with boldness in his philosophical speculations. From his new essay the general public learnt, not without surprise, how little the most experienced botanists are agreed amongst themselves as to the limits of species, and to what an extent these limits are a mere matter of opinion, even amongst those who believe that species have remained unchanged since their creation, and will remain immutable as long as they continue on the globe. As conspicuous evidence of this he stated that the number of known

species of flowering plants is assumed by some to be under 80,000, and by others over 150,000.*

Dr. Hooker showed that in proportion as we study the same plant under varied conditions and in distant regions, it becomes more and more difficult to define its precise specific characters; also that in the flora of every country there are some groups of species which are apparently unvarying, others which on the contrary run so much one into another that the whole group may be regarded as a continuous series of varieties between the terms of which no hiatus exists such as might allow of the intercalation of any intermediate variety. The genera Rubus, Rosa, Salix, and Saxifraga afford conspicuous examples of these unstable forms; Veronica, Campanula, and Lobelia of comparatively stable ones. At the same time he points out in accordance with Mr. Darwin's theory how the extinction of a certain number of the intermediate races by destroying the transitional links would facilitate the classification of the remaining species, and hints that we may be indebted to such extinction in past times for whatever facility we now enjoy of resolving plants into distinct species, genera, and orders. 'The mutual relations,' he observes, 'of the plants of each great botanical province, and in fact, of the world generally, are just such as would have resulted if variation had gone on operating throughout indefinite periods, in the same manner as we see it act in a limited number of centuries, so as gradually to give rise in the course of time to the most widely divergent forms.'

When we reflect that this statement was made after a study of the characters and geographical distribution of tens of thousands of species, we feel disposed at once to declare that a theory which is in harmony with so many facts must be true; but if so, we have to enquire how it happens that so many naturalists, of undoubted ability and knowledge, have always held and still believe that species have been constant from the beginning. In reference to this question, Dr. Hooker admits that species are realities and may be treated as if they were permanent and immutable; for the forms and characters, at least of the great majority of them, may be

* Flora of Tasmania, p. iii.

faithfully transmitted through thousands of generations, and may have remained constant within the range of our experience. 'But our experience,' he remarks, 'is so limited that it will not account for a single fact in the present geographical distribution, or origin of any one species of plant, nor for the amount of variation it has undergone, nor will it indicate the time when it first appeared nor the form it had when created.'*

* Hooker, Flora of Tasmania.

CHAPTER XXXVI.

VARIATION OF PLANTS AND ANIMALS UNDER DOMESTICATION VIEWED AS BEARING ON THE ORIGIN OF SPECIES.

DOMESTIC RACES, HOWEVER DIVERGENT, BREED FREELY TOGETHER—REMOTE ANTIQUITY OF SOME ARTIFICIALLY FORMED RACES—SELECTION, BOTH UNCONSCIOUS AND METHODICAL, VERY INFLUENTIAL IN FORMING NEW RACES—THE CHARACTERS OF SOME RACES OF THE DOMESTICATED PIGEON OF GENERIC VALUE—REVIVAL OF LONG-LOST CHARACTERS IN THE OFFSPRING OF CROSS-BREEDS—MULTIPLE ORIGIN OF THE DOG—INHERITED INSTINCTS—VARIATION OF THE GOLD FISH AND SILKWORM—MAN CAUSES PARTICULAR PARTS OF AN ANIMAL OR PLANT TO VARY WHILE OTHER PARTS CONTINUE UNALTERED—MAIZE—CABBAGE—ARE THERE ANY LIMITS TO THE VARIABILITY OF A SPECIES?—OBEDIENCE TO MAN UNDER DOMESTICATION OFTEN MERELY A NEW ADAPTATION OF A NATURAL INSTINCT—'FERAL' VARIETIES DO NOT REVERT TO THE EXACT LIKENESS OF THE ORIGINAL WILD STOCK—HOW FAR DO DOMESTIC RACES DIFFER FROM WILD SPECIES IN THEIR CAPACITY TO INTERBREED?—HYBRIDISATION OF ANIMALS AND PLANTS—HERMAPHRODITE PLANTS NOT USUALLY SELF-FERTILISED—WHETHER THE DISTINCTNESS OF SPECIES CAN BE TESTED BY HYBRIDITY—TENDENCY OF DIFFERENT RACES OF DOMESTIC CATTLE AND SHEEP TO HERD APART—PALLAS ON DOMESTICITY ELIMINATING STERILITY—CORRELATION OF GROWTH.

Domestic races, however divergent, breed freely together.—We have seen that the indefinite modifiability of species in the course of thousands of generations, and under gradually altered conditions in the organic and inorganic world, is a question which has been seriously entertained by naturalists ever since the beginning of the present century. The changes brought about by the breeder and horticulturist, and the new races to which they have given origin, have always been appealed to in support of this theory of unlimited variability. It may be said that man, in every stage of his social progress, has been engaged in conducting with much patience and at enormous cost, a grand series of experiments to ascertain how far it is possible to make the descendants of common parents, both in the animal and vegetable kingdoms, deviate from their original type. In pur-

suing this course he has by no means confined his attention to plants and animals which minister to his wants, but he has sometimes gone on for thousands of years simply for his amusement, trying how far he could alter certain species —the pigeon, for example, or some flowering plants such as the rose.

The opponents of the doctrine of transmutation have always objected to arguments founded on the results of such experiments, that, in spite of the skill and perseverance of the breeder, agriculturist and florist, man has never succeeded in giving origin to one new species. For however far some of the new races may have diverged from the parent stock or from each other, they have always continued to breed freely together and produce fertile offspring, whereas the hybrids which result from the union of two distinct species in nature are always sterile.

Before we can decide on the weight which we must attach to such an objection, we must consider not only the nature and extent of the changes which have been effected in species under domestication and culture, but also the facility of obtaining hybrid plants and animals of wild species, and the different degrees of sterility of the hybrids when obtained. The whole subject of the variation of domesticated animals and cultivated plants has been lately treated of, with so much ability and in such detail, by Mr. Darwin in his work on Variation,* that I cannot do better than refer the reader to his clear statements of the facts and of their bearing on his theory of the 'Origin of Species.' In this chapter, besides repeating much that I advanced in former editions, I shall allude briefly to some of the valuable observations and experiments which he has made, and the theoretical conclusions to which they point.

Remote antiquity of some artificially formed races.—The explorations so actively carried on within the last twenty years in the Swiss lake-dwellings, and an examination of the remains of animals and plants there preserved, have shown that domesticated races of the dog, the ox, and the sheep, and cultivated varieties of several cereals and of many fruits,

* The Variation of Plants and Animals under Domestication: 1867.

had been formed in Central Europe in the Neolithic age, or before the use of metals was yet general. The antiquity which we are thus called upon to assign to the culture of certain plants need not surprise us, if Mr. Darwin is correct in his opinion that man in a barbarous state is naturally led to discover the useful properties of all wild plants by the frequently recurring famines to which all savage tribes are exposed; for when in danger of starving he is compelled to try as food every kind of fruit, leaf, and root. By this means the nutritious, stimulating, and medical qualities of the most unpromising species are brought to light.

It might have been thought that the seeds of wild grasses were too minute to afford much temptation for men in a rude state of society to cultivate them for food; but it seems that both Barth and Livingstone* observed the natives in different parts of Africa collecting the seeds of wild grasses, and eating them; from which practice it would be an easy step to pass to the sowing of some of them near their usual haunts, and eventually to the selection for seed of those varieties which yielded the largest crops. The great number of cultivated grasses or cereals, and the difficulties which botanists encounter when they endeavour to trace them to their original stocks, or to the wild species from which they have sprung, become more intelligible if we suppose that they have undergone considerable modifications under culture in prehistoric times.

It has often been remarked that we do not owe a single useful plant to Australia or the Cape of Good Hope, or to New Zealand, or to America south of the Plata. On this subject Mr. Darwin observes, that we must by no means infer that in these countries no native plants have proved useful to savage man. Dr. Hooker, indeed, enumerates no less than 107 native species† which are used even by the Australians. But the small advantage which civilised man has hitherto derived from the regions above alluded to simply demonstrates that wild plants cannot compete with those which have been improved by cultivation for a long series of generations.

* Cited by Darwin, 'On Variation of Animals,' &c., 1867, p. 308.

† Flora of Australia, Introduction, p. cx.

A skilful botanist who should see for the first time our finest varieties of apples, peaches, pears, and plums, would be unable to guess from what species of wild trees they had been derived.

De Candolle mentions no less than thirty-three useful plants which we owe to Mexico, Peru, and Chili, among which the maize and potato are conspicuous; and Tschudi describes two forms of maize no longer known in Peru, which were taken from the tombs of the Incas,* and which had become extinct before the arrival of the Spaniards in South America. But strange to say, no botanist has yet been able to trace the maize, which had evidently been cultivated from a very remote period, to any wild aboriginal parent stock.

The slowness with which improved varieties of native plants have been brought into existence may be inferred from the researches of Oswald Heer with respect to the fruits belonging to the Swiss lake-dwellers of the later Stone period. They had collected wild crabs, sloes, bullaces, elderberries, hips of roses and beech-mast differing but slightly from those which we know in a wild state. They had also five kinds of wheat and three of barley, mostly inferior in size to ours. Among them was the wheat commonly called Egyptian; a fact leading to the inference that the lake-dwellers had either come originally from the south or had intercourse with some southern people. So in regard to the domesticated animals of the same lake-dwellers, they do not agree exactly with any of our breeds. Thus for example, they had two kinds of cattle which are considered as modifications of two species or races which then existed in a wild state—namely, *Bos primigenius* and *Bos longifrons*; but, although they were modifications of these original types, they cannot be identified with any existing European breeds. Their dog also differed from ours, or from that of the later Bronze period, and according to Rütimeyer was of a middle size, and equally remote from the wolf and the jackal. They had also a small breed of sheep with long and thin legs and with horns like those of a goat, which was not exactly similar to any one of the races now known.

Selection, both unconscious and methodical, very influential

* Cited by Darwin, 'On Variation,' &c., p. 320.

in forming new races.—When the art of the breeder has been greatly perfected, he is able to bring about very important changes in a short time. He has no power either of causing or preventing the numerous varieties which nature presents to him among individuals born of the same parents. But he can choose those which best suit his purpose, and breed from them, while he destroys those varieties which are less valuable. In the next generation he again picks out those individuals which possess the desired qualities in a somewhat more marked degree; and so goes on accumulating these differences till he produces a breed which answers to some preconceived idea formed by him. He can discriminate trifling variations both in animals and plants which an uneducated eye cannot appreciate. The variations which are thus intensified become fixed by inheritance, and permanent races are formed by a process technically called 'selection.' But there is another kind of selection, termed 'unconscious' by Mr. Darwin, which perhaps acts more powerfully in the long run, both in a rude and civilised state of society. The savage, when pressed by hunger, is often driven to feed on his dogs; in which case, if he is able to retain any of them, he preserves such as are most useful to him in the chase. So in a very early state of agriculture, the seeds and fruits of those varieties which offer some advantage over others, by the abundance of their produce or the quality or flavour of the nutriment they afford, will be sown by preference, whereas the seeds of less prized varieties will be consumed. For man is always called upon to decide which individuals shall be spared as a stock from which to breed, so many more being always born into the world than there is room or food for. Mr. Darwin supposes that, even in the most advanced state of society, the influence of unconscious selection acts more powerfully than methodical selection.

Our present bull-dogs, he observes, are different from those formerly used for baiting bulls, being of smaller size and altered in shape, now that the old sport has been given up. Our fox-hounds differ from the old English hound, and our greyhounds have become lighter. Our enormous dray-horses have been produced from some ancient bulky race through

the unconscious selection, carried on during many generations in Flanders and England, of the most powerful and heaviest horses, without the least intention or expectation of creating our present elephant-like breed.* After the introduction into England of some Arab horses, the methodical selection of the swiftest individuals gradually produced the English race-horse. But even this change has been partly effected unconsciously, by the general wish to breed as fine horses as possible, without any intention to give to them their present character.

The characters of some races of the domesticated pigeon of generic value.—Domestic pigeons afford a most striking illustration of the great divergence from the original type, the rock pigeon (*Columba Livia*), which man has brought about in the course of time. These birds have been domesticated for thousands of years in Egypt and India, and they afford remarkable facilities for the production of distinct breeds, as the male and female birds can be easily mated for life, and the different varieties kept together in the same aviary. More than 150 distinct races have received names, all breeding true; and at least a score of these, says Mr. Darwin, might be named, which, if shown to an ornithologist, and he was told they were wild birds, would be ranked by him as well-defined species, while some of them, such as the carrier, short-faced tumbler, pouter and fan-tail, would not even be placed in the same genus. From historical details which have come down to us of the principal races of the pigeon as they were known in India before the year 1600, it appears that these races, although they might have been classed in the same groups as our present breeds, had not at that time diverged in so great a degree from their aboriginal common parent, the wild rock pigeon.

Pigeon-fanciers in forming new varieties have confined their attention to external characters—such as the length of the beak, the number or length of the tail feathers, the colour of the plumage, and the general shape of the body, yet they have sometimes unintentionally produced modifications in

* Darwin 'On Variation,' chap. xx. p. 212.

the internal bony framework of the species. Thus while they have given a longer body to the pouter, they have unintentionally augmented the number of its sacral and caudal vertebræ, and the breadth of the ribs as well as the size of the breast-bone. In the fan-tail they have increased considerably the length and number of the caudal vertebræ; and, what is still more worthy of note, in several breeds the whole skull differs in its proportions and outline from that of the rock pigeon.

So many passages have been traced between the most divergent varieties above alluded to and the wild *Columba Livia*, that ornithologists do not hesitate to recognise this species as the common progenitor of them all. Another curious proof of such a derivation is afforded by crossing distinct breeds and finding in the offspring some peculiar characters of the rock pigeon, especially in the plumage, which neither of the parent races possessed.* Thus the blue slaty colour, or dark bars, on the wings and tail, and the white edging of the outer tail feathers of the original *Columba Livia*, are produced in the mongrel offspring of the carrier and fan-tail, although all these characters have often been in abeyance in both of the parent stocks for a hundred or more generations. Mr. Darwin has tested the truth of this singular principle of atavism, by experiment, in the case of pigeons, and has also obtained analogous results, by pairing some of the most distinct varieties of the common fowl; as, for example, a black Spanish cock and a white silky hen, two ancient and pure breeds in which there was not a trace of the red colour proper to the plumage of the wild *Gallus bankiva*, a Himalayan species, which has always been supposed to be the original of our domestic fowls. In many of the young obtained from such a cross the peculiar orange-red colour was conspicuous.†

Revival of long-lost characters in the offsprings of cross-breeds.—Why the act of crossing should tend to evoke characters which had long been lost in each of the parent races, is one of the most wonderful enigmas which the attributes of inheritance present to us. By what favourable combination

* Darwin 'On Variation,' vol. i. p. 200. † Ibid. p. 241.

of circumstances can we suppose these characters, which must have been lying latent in so many intermediate generations, to be thus made again to manifest themselves? In some cases they are developed alternately in successive generations, in others at longer intervals.

The composition of the molecules which form the germ-cells of animals and plants, and their mode of multiplication and transmission from one generation to another, has been a favourite subject of speculation ever since the time of Buffon and Bonnet. More recently (1849), Professor Owen has treated of this subject in his memoir on 'Parthenogenesis,' and Mr. Herbert Spencer has speculated on the manner in which the atoms or physiological units composing the fertilised germ of an animal or plant may unfold into organisms and become the means of transferring the qualifications of the parent to the offspring.* The new hypothesis suggested by Mr. Darwin, and which he has called 'Pangenesis,' coincides in many respects with that of Mr. Spencer, and cannot be fully understood without reference to the luminous and detailed explanations of it given by Darwin in the concluding chapters of his work on Variation.† He assumes that the germ-cells of animals and plants are capable of generating minute bodies, termed by him cell-gemmules, which become diffused through all parts of an organism, and are capable of multiplying and uniting with others like themselves, and when this union does not occur, may remain in a dormant state. Their increase may take place after the usual manner of growth in all living beings, according to which entire limbs are sometimes reproduced in the lower animals after they have been cut off, or as wounds are healed by the formation of new flesh, or as a portion of the leaf of a plant may be developed into a perfect individual. The cell-gemmules remaining undeveloped for many generations, may be compared to seeds lying dormant in the earth, or to rudimentary organs which, though useless, may be inherited for an indefinite succession of generations, or as long as an entire species endures on the earth.

* Principles of Biology, vol. i. chaps. iv. and viii.

† Darwin 'On Variation,' chaps. xxxvii. and xxxviii.

Before this new hypothesis was started, it was sufficiently difficult to conceive how a microsopic cell or ovule, so minute as to be often invisible to the naked eye, and in some cases requiring the aid of a powerful microscope to be made visible, should contain within it not only the characters of the species, but many of the peculiarities of one or both parents, including some of their acquired individual habits and instincts. But now we are called upon, in addition, to imagine that there are innumerable other molecules, in each germ or ovule, in which the characteristics of remote progenitors may also be present. As bearing on the question of the possible minuteness of particles of organic matter, I shall have to refer in a future chapter (Chap. XL.) to the ten million sporules of a single fungus which were counted by Fries. A still more lively idea of the possible diminutiveness of material atoms may be gained by reflecting on the manner in which the air is often perfumed or tainted throughout large spaces by the odour of a plant or animal, and how the contagious particles of certain diseases float unseen in the atmosphere, until they are at last received within a human body, where they rapidly increase and act powerfully.

Assuming, then, that the number of cell-gemmules in an undeveloped embryo may be almost infinite in number, we have to explain how some of these, after having been long transmitted in a latent state, may suddenly multiply and gain an ascendency when individuals belonging to two distinct races are crossed. Among other facts which are somewhat analogous, we are reminded that, although there is frequently in the offspring a fusion of all the characters of the parents, yet occasionally some of the characters of one parent are exclusively transmitted to one of the children and those of the other parent to another. The characters of one parent sometimes prevail in all the offspring to the exclusion of those of the other. When Gärtner crossed white and yellow-flowered varieties and species of mullein (*verbascum*), these colours never became blended, but the offspring bore either pure white or pure yellow blossoms. This must depend on some principle of the affinity of similar and the repulsion of dissimilar atoms. The cell-germs derived from two

individuals of distinct races may not readily unite, or not in sufficient numbers for the reproduction of the characteristic attributes of the two parents; they may be antagonistic and neutralise each other's power in such a way as to allow the gemmules derived from a remote progenitor to multiply suddenly, gaining such an ascendency as to revive certain peculiarities of the original stock which had remained long in abeyance.

Multiple origin of the dog.—In regard to the origin of the various canine races which have been domesticated by man in all parts of the world, there is still no small diversity of opinion. Mr. Darwin, after an elaborate analysis of all that has been written on the subject, inclines to the belief which Pallas entertained of the multiple origin of the dog, more than one wild species having been blended together to produce the very distinct races which we now possess. The celebrated John Hunter maintained that the wolf, the dog, and the jackal were all of one species; because he had found, by two experiments, that the dog would breed both with the wolf and the jackal; and that the mule, in each case, would breed again with the dog. In these cases, however, it may be observed, that there was always one parent at least of pure breed, and no proof was obtained that a true hybrid race could be perpetuated.

It was formerly supposed that the period of gestation in the dog and the wolf differed slightly; but experiments have not borne out this opinion; and Professor Owen has been unable to confirm the alleged difference in the structure of a part of the intestinal canal. It seems scarcely to admit of a doubt that both the jackal, and more than one species of wolf, have been occasionally crossed with the dog.

The main argument in favour of the different breeds of the dog being the descendants of distinct wild stocks is their resemblance, says Darwin, in various countries to indigenous species still existing there.* Thus the domestic dogs of the American Indians resemble North American wolves. The shepherd-dog of Hungary is very like the European wolf; the domestic dog of Asia resembles the jackal. But Mr.

* Darwin 'On Variation,' chap. i. p. 20.

Wallace has suggested to me that evidence of this nature loses much of its weight when we take into consideration some cases of modification given by him and by Mr. Darwin, and cited by Mr. Mivart in his 'Genesis of Species.'* Many quite distinct species of butterflies are shown to be similarly modified in the same localities; in some districts acquiring more elongate wings, in others losing their tails, in others again becoming enlarged or diminished in size. No less than twenty-nine kinds of American trees have been shown by Mr. Meehan to differ from their nearest European allies, all in the same manner; and M. Costa has stated that young English oysters taken to the Mediterranean at once altered their manner of growth, and formed prominent diverging rays or ribs on the shell, like those proper to the Mediterranean oyster. A yet more pertinent illustration of this law is afforded by the Cape hunting dog (*Lycaon venaticus*), and the Aard wolf (*Proteles cristatus*), animals which inhabit the same region as the hyænas, and curiously resemble them in external form and colouring, although differing from hyænas in such important structural characters, that the former is placed in a distinct genus, and the latter constitutes, according to Professor Flower, a peculiar and very isolated family. If, therefore, certain localities can impress upon whole groups of species a uniform *facies*, Mr. Wallace considers it more probable that the dogs of various regions have been thus modified so as to correspond to native foxes, wolves, and jackals, than that they should have been descended from such very distinct species, and have mysteriously acquired the power of breeding together and producing fertile offspring, which those species themselves do not possess.

But, even if the intercrossing of several original wild stocks may have increased the total number and diversity of our breeds, it cannot, says Darwin, explain the origin of such extreme forms as thoroughbred greyhounds, bloodhounds, bulldogs, Blenheim spaniels, terriers and pugs, none of which are known to have been kept by savages, and which are the product of breeding in civilised countries. The difference

* Pp. 83–88.

in the form of the skulls in some of these races is admitted by Cuvier to be sometimes more than generic; in some varieties there is an additional pair of molars in the upper jaw (see p. 265); and some, like the Turkish dogs, are deficient in the number of their molars; the mammæ also vary from seven to ten in number. Dogs have properly five toes in front, and four behind, but a fifth toe is often added, together with a fourth cuneiform bone. Man, says Darwin, if he had cared about the number of their molar teeth, mammæ or digits, could, by selection, have fixed these characters, in the same way as he has given additional horns to certain breeds of sheep, and an additional toe and feathers to the Dorking fowl; but at present these peculiarities have merely accompanied changes in form, fleetness, size, strength, and other characters which the breeder has purposely fixed.

Inherited instincts. — It is evident that these new races could not be artificially produced if the individual peculiarities of one generation were not transmitted by inheritance to the next. Even newly acquired habits and instincts are often so transmitted, as was beautifully illustrated by a race of dogs employed for hunting deer in the platform of Santa Fé, in Mexico. The mode of attack, observes M. Roulin, which they employ consists in seizing the animal by the belly and overturning it by a sudden effort, taking advantage of the moment when the body of the deer rests only upon the fore-legs. The weight of the animal thus thrown over is often six times that of its antagonist. The dog of pure breed inherits a disposition to this kind of chase, and never attacks a deer from before while running. Even should the deer, not perceiving him, come directly upon him, the dog steps aside and makes his assault on the flank; whereas other hunting dogs, though of superior strength, and general sagacity, which are brought from Europe, are destitute of this instinct. For want of similar precautions, they are often killed by the deer on the spot, the vertebræ of their neck being dislocated by the violence of the shock.*

A new instinct has also become hereditary in a mongrel

* M. Roulin, Ann. des Sci. Nat., tom. xvi. p. 16. 1829.

race of dogs employed by the inhabitants of the banks of the Magdalena almost exclusively in hunting the white-lipped pecari. The address of these dogs consists in restraining their ardour, and attaching themselves to no animal in particular, but keeping the whole herd in check. Now, among these dogs some are found, which, the very first time they are taken to the woods, are acquainted with this mode of attack; whereas, a dog of another breed starts forward at once, is surrounded by the pecari, and, whatever may be his strength, is destroyed in a moment.

Some of our countrymen engaged about the year 1825 in conducting one of the principal mining associations in Mexico, that of Real del Monte, carried out with them some English greyhounds of the best breed, to hunt the hares which abound in that country. The great platform which is here the scene of sport is at an elevation of about 9,000 feet above the level of the sea, and the mercury in the barometer stands habitually at the height of about nineteen inches. It was found that the greyhounds could not support the fatigues of a long chase in this attenuated atmosphere, and before they could come up with their prey, they lay down gasping for breath; but these same animals have produced whelps which have grown up, and are not in the least degree incommoded by the want of density in the air, but run down the hares with as much ease as the fleetest of their race in this country.

The fixed and deliberate stand of the pointer has with propriety been regarded as a mere modification of a habit, which may have been useful to a wild race accustomed to wind game, and steal upon it by surprise, first pausing for an instant, in order to spring with unerring aim. The faculty of the retriever, however, may justly be regarded as more inexplicable and less easily referable to the instinctive passions of the species. M. Majendie, says a French writer in a recently published memoir, having learnt that there was a race of dogs in England which stopped and brought back game of their own accord, procured a pair, and, having obtained a whelp from them, kept it constantly under his eyes, until he had an opportunity of assuring himself that,

without having received any instruction, and on the very first day that it was carried to the chase, it brought back game with as much steadiness as dogs which had been schooled into the same manœuvre by means of the whip and collar.

The power of man to produce new races of animals by selection, has been by no means confined to the mammalia and birds. The Chinese have kept gold fish (*Cyprinus auratus*) for ornament or curiosity from a remote period, and it is suspected that the golden colour is not characteristic of the species in a state of nature. Yarrell mentions that descriptions and coloured drawings of no less than 89 varieties have been given by Sauvigny, some destitute of dorsal fins, others having a double anal fin or a triple tail. Of these, many, says Darwin, may be called monstrosities, for it is difficult to draw a strict line between a variation and a monstrosity.

If we turn from the vertebrata to the invertebrata, we find here again that selection is capable of producing distinct races in the class of insects, as in the case of the common silk-moth (*Bombyx mori*), which is believed to have been domesticated in China nearly 3,000 years before our era. It was brought to Constantinople in the sixth century, whence it was carried into Italy, and in the year 1494 into France.* The nature of the food given to the caterpillar influences to a certain extent the character of the breed. Great care is taken in India and Europe in the selection of the eggs of those moths whose caterpillars have produced the best cocoons. The silk is usually yellow, but sometimes white, and, by careful selection, in the course of sixty-five generations the proportion of yellow cocoons in France was greatly reduced. The abdominal feet of the caterpillars which yield white cocoons are, according to Quatrefages, always white, while the feet of those which give yellow cocoons are invariably yellow, and there is a corresponding difference in the tint of the eggs.

Man causes particular parts of an animal or plant to vary

* Godron, 'De l'Espèce,' 1859, tom. i. p. 460; and see Darwin 'On Variation,' vol. i. p. 300.

while other parts may continue unaltered.—The possibility of obtaining particular breeds and fixed varieties of animals and plants depends on the fact that variations occur in almost any required direction if a vast number of individuals are produced. It is also found that one form of variation may usually be accumulated in successive generations by selection, without the other characters of the species being materially affected. Cows are wanted which may give us an increased quantity of milk, sheep which may yield finer wool, poultry which may have a habit of continually laying eggs; and these qualities are often obtained without perceptibly changing in any other respect the habits or organisation of the same races.

In the case of the maize and the vine, we alter the seed and the fruit without changing the leaves, whereas in the foliage of the mulberry, cultivated for the sake of the silkworm, new varieties have been formed, the fruit remaining the same. In the cabbage the leaves have undergone wonderful transformations, as have the tubers in the potato and the roots in the carrot, while the characters of the flowers in all have remained unaltered. The modifications produced in the seeds of the maize deserve especial notice. The different races vary in height from eighteen inches to as many feet, and the whole ear in one variety is more than four times as long as in another dwarf kind. The seeds are coloured white, pale yellow, orange, red, violet, or streaked with black. Mr. Darwin found that a single grain in one variety equalled in weight seven grains of another. The tall kinds grown in southern latitudes and exposed to great heat require from six to seven months to ripen their seed, whereas the dwarf kinds grown in northern and colder climates require only from three to four months.*

In North America the maize has been gradually cultivated farther and farther northward, in which case the changes induced by an alteration of climate have been added to those due to selection. In this plant the results of inherited acclimatisation are very striking. Metzger obtained the

* Metzger die Getreidearten, 1841, p. 206, cited by Darwin 'On Variation,' vol. i. p. 321.

seed of a variety called *Zea altissima* from the warmer parts of America, and raised it in Germany, and the first year the plants were twelve feet high and few seeds were perfected. The lower seeds in the ear kept true to their proper form, but the upper ones became slightly changed. In the second generation the plants were from nine to ten feet in height, and the seeds had changed from white to yellow and were more rounded in form. In the third generation nearly all resemblance to the original and very distinct parent form was lost. In the sixth generation this maize, which continued to be cultivated near Heidelberg, could only be distinguished from the common European kind by a somewhat more vigorous growth. 'The fact,' says Mr. Darwin, 'affords the most remarkable instance known to me of the direct and prompt action of climate on a plant.'

Several hundred varieties of the vine, characterised by differences in their fruit, have been reared in hothouses, or cultivated for wine, while the mulberry, both in France and India, has given rise to as many varieties in the texture and quality of the leaves, characters which have been rendered constant by selection. If man had reversed this treatment, he might doubtless have produced endless changes in the leaves of the vine, the grapes remaining unaltered, and a great many races characterised by different fruits in the mulberry, while the leaves, being neglected, would not have undergone any marked modification from the type of the original plant.

A bitter plant (*Brassica oleracea*), with wavy sea-green leaves, having a flower like mustard or wild charlock, has been taken from the sea-side, and transplanted into the garden, where it has lost its saltness, and has been metamorphosed into many distinct vegetables, among others the red cabbage and the cauliflower, which are as unlike each other as is each to the parent plant. In certain countries plants belonging to the order of Cruciferæ which are generally herbaceous become developed into trees, so the cabbage in the island of Jersey has acquired a woody stem not unfrequently from ten to twelve feet in height. The stalk of one which measured sixteen feet in height had its spring shoots at the top occu-

pied by a magpie's nest. The wood of the same variety is sometimes used for walking sticks, and even for rafters. These effects result from particular culture and peculiarities of climate. What is worthy of note, says Darwin, is the very trifling difference in the flowers, seed-pods, and seeds of the cabbage which accompanies the wonderful metamorphosis which man has brought about in the shape, size, colour, and growth of the leaves and stem. What a contrast is here presented to the changes in the corresponding parts in the varieties of maize and wheat! 'The explanation is obvious: the seeds alone are valued in our cereals, and their variations have been selected; whereas the seeds, seed-pods, and flowers have been utterly neglected in the cabbage, whilst many useful variations in their leaves and stems have been noticed and preserved from an extremely remote period, for cabbages were cultivated by the old Celts.' *

Among the changes in external conditions of which florists avail themselves in order to produce new varieties those of the soil must not be overlooked. The production of blue instead of red flowers in the *Hydrangea hortensis*, illustrates the immediate effect of certain soils on the colours of the calyx and petals. In garden-mould or compost, the flowers are invariably red; in some kinds of bog-earth they are blue; and the same change is always produced by a particular sort of yellow loam.

Whether there are definite limits to the variability of a species.—In former editions of this work (from 1831 to 1853),† I contended that there are limits to that deviation from an original type of which species are susceptible. My argument was founded chiefly on the rapid rate at which we may bring about considerable modifications in a brief period in domesticated animals and cultivated plants, and the slow progress which we can afterwards make in modifying the same races when our experiments are persevered in for a great many generations. In illustration of this principle I observed, that when man uses force or stratagem against wild animals, the persecuted race soon becomes more cau-

* Darwin 'On Variation,' vol. i. p. 324.

† 'Principles of Geology,' 1st edition, 1831, vol. ii. chap. iii. p. 37, and 9th edition, chap. xxxv. p. 592.

tious, watchful, and cunning; new instincts seem often to be developed, and to become hereditary in the first two or three generations: but let the skill and address of man increase, however gradually, no farther variation can take place, no new qualities are elicited by the increasing dangers. The alteration of the habits of the species has reached a point beyond which no ulterior modification is possible, however indefinite the lapse of ages during which the new circumstances operate. Extirpation then follows, rather than such a transformation as could alone enable the species to perpetuate itself under the new state of things.

But Mr. Darwin has shown that even in those species such as the pigeon, our common cattle, sheep or pigs, which have been made to vary by selection from the remotest periods, there are no signs of a positive limit having been reached beyond which no farther change can be brought about. All have been altered within quite modern times, and 'the tendency to general variability seems unlimited.'*

It has also been pertinently remarked by Mr. Wallace that the amount of change in any one direction may at first be comparatively rapid; as when in the case of the race-horse, we begin to select certain varieties with a view of increasing speed, and afterwards fail in our efforts materially to raise the standard, for however many years we may expend wealth and energy in the attempt. The real question, he observes, is not whether indefinite and unlimited change in any or all directions is possible, but whether man can bring about such differences as do occur in nature by accumulating variations or by selection. 'All the swiftest animals—deer, antelopes, hares, foxes, lions, leopards, horses, zebras, and many others—have reached very nearly the same degree of speed. Although the swiftest of each must have been for ages preserved and the slowest must have perished, we have no reason to believe that there is any advance of speed. The possible limit under existing conditions, and perhaps under possible terrestrial conditions, has been long reached.'† But in the English race-

* Darwin 'On Variation,' &c. p. 416.

† Wallace, Quart. Journ. of Science, October, 1867, p. 486; and 'Contributions to the Theory of Natural Selection,' p. 292.

horse we have been enabled to produce a variety surpassing in swiftness its own wild progenitor and all the other equine species.

Obedience to man under domestication often a mere adaptation of a natural instinct.—We may also very easily exaggerate the amount of change which seems to be brought about in a few generations. Frederick Cuvier* has clearly pointed out one source of deception relating to alterations which we may fancy we have wrought in the instincts and dispositions of animals. An animal in domesticity, he observes, is not essentially in a different situation, in regard to the feeling of restraint, from one left to itself. It lives in society without constraint, because, without doubt, it was a social animal; and it conforms itself to the will of man, because it had a chief, to which, in a wild state, it would have yielded obedience. There is nothing in its new situation that is not conformable to its propensities; it is satisfying its wants by submission to a master, and makes no sacrifice of its natural inclinations. All the social animals, when left to themselves, form herds more or less numerous; and all the individuals of the same herd know each other, are mutually attached, and will not allow a strange individual to join them. In a wild state, moreover, they obey some individual, which, by its superiority, has become the chief of the herd. Our domestic species had, originally, this sociability of disposition; and no solitary species, however easy it may be *to tame it*, has yet afforded true domestic races. We merely, therefore, develope, to our own advantage, propensities which propel the individuals of certain species to draw near to their fellows.

The sheep which we have reared is induced to follow us, as it would be led to follow the flock among which it was brought up; and, when individuals of gregarious species have been accustomed to one master, it is he alone whom they acknowledge as their chief—he only whom they obey. 'The elephant allows himself to be directed only by the carnac whom he has adopted; the dog itself, reared in solitude with its master, manifests a hostile disposition towards all others; and everybody knows how dangerous it is to be

* Mém. du Mus. d'Hist. Nat.; Jameson, Ed. New Phil. Journ., Nos. 6, 7, 8.

in the midst of a herd of cows, in pasturages that are little frequented, when they have not at their head the keeper who takes care of them.

'Everything, therefore, tends to convince us, that formerly men were only, with regard to the domestic animals, what those who are particularly charged with the care of them still are—namely, members of the society which these animals form among themselves; and that they are only distinguished, in the general mass, by the authority which they have been enabled to assume from their superiority of intellect. Thus, every social animal which recognises man as a member, and as the chief of its herd, is a domestic animal. It might even be said that, from the moment when such an animal admits man as a member of its society, it is domesticated, as man could not enter into such a society without becoming the chief of it.'*

But the ingenious author whose observations I have here cited, admits that the obedience which the individuals of many domestic species yield indifferently to every person, is without analogy in any state of things which could exist previously to their subjugation by man. Each troop of wild horses, it is true, has some stallion for its chief, who draws after him all the individuals of which the herd is composed; but, when a domesticated horse has passed from hand to hand, and has served several masters, he becomes equally docile towards *any person*, adopting as it were the whole human race as his leader.

Every troop of wild elephants has a leader who directs their movements with much caution, and takes care that none of them straggle from the herd. In India this animal rarely breeds in captivity, although, according to Mr. Crawfurd, in Ava, where the females are allowed to roam somewhat freely in the forests, they breed in a half-domestic state. In general it is found to be the best economy to capture full-grown individuals in a wild state, and in a few years after they are taken, sometimes, it is said, in a few months, their education is completed. They who have had oppor-

* Mém. du Mus. d'Hist. Nat.

tunities of observing them in their native forests are by no means surprised at the sagacity which they display after they have accommodated themselves to the society of man, to whom they render obedience, not by acquiring any new instincts, but simply in conformity to faculties proper to them in a wild state.

The tameness of some animals—in the case of cattle, goats, and deer, for example—after they have been reclaimed and improved by selection for two or three generations, is another change of which we may be in danger of overrating the importance. The first savages who wandered into new districts probably found most of the animals free from any apprehension of danger from man. Mr. Darwin relates that in the islands of the Galapagos Archipelago, placed directly under the equator, and nearly 600 miles west of the American continent, all the terrestrial birds, as the finches, doves, hawks, and others, are so tame that they may be killed with a switch. One day, says this author, 'a mocking-bird alighted on the edge of a pitcher which I held in my hand, and began quietly to sip the water, and allowed me to lift it with the vessel from the ground.' Yet formerly, when the first Europeans landed, and found no inhabitants in these islands, the birds were even tamer than now: already they are beginning to acquire that salutary dread of man which in countries long settled is natural even to young birds, which have never received any injury. So in the Falkland Islands, both the birds and foxes are entirely without fear of man; whereas, in the adjoining mainland of South America, many of the same species of birds are extremely wild; for there they have for ages been persecuted by the natives.*

Sir John Richardson informs us, in his able history of the habits of the North American animals, that, 'in the retired parts of the mountains, where the hunters had seldom penetrated, there is no difficulty in approaching the Rocky Mountain sheep, which there exhibit *the simplicity of character so remarkable in the domestic species*; but where they have been often fired at, they are exceedingly wild, alarm their companions, on the approach of danger, by a hissing noise, and

* Darwin's Journ. in Voyage of H.M.S. Beagle, p. 475.

scale the rocks with a speed and agility that baffle pursuit.' *

'Feral' varieties do not revert to the exact likeness of the original stock.—It is an old and received opinion that if any domesticated animals or cultivated plants are abandoned by man and allowed to run wild or become 'feral,' they will revert to the exact likeness of their aboriginal parent stock. But this seems to be only true to a limited extent. It was before remarked (p. 281) that such 'feral' animals can only compete with their fellows in the struggle for life by losing most of the characters which they have acquired in a state of domesticity.

Our quickly fattening pigs, says Mr. Wallace, our short-legged sheep, cattle without horns and pouter pigeons, would soon be annihilated if man's protection was withheld from them. In a few generations the boar when compelled to search for food recovers his long tusks and the full exercise of all his organs; reverting in the general shape of his body, the length of his legs and of his muzzle, to the type of the wild boar.

His reversion to the likeness of the parent stock, says Darwin, is probably more complete than that of other domesticated animals which run wild, but there is no evidence to show that it is ever perfect. There are two main types of the domestic pig—one supposed to come from the European *Sus scrofa*, and the other from the Indian *Sus Indica*. These varieties or species seem not yet to have been distinctly recognised in a feral state, and the feral pigs of S. America, Jamaica, and New Granada, have each some peculiarities.† Under new climatal and other conditions they vary, but they can only stand their ground by reacquiring many lost characters which belonged to the original wild species.

It is very commonly believed that when the seeds of fruit-trees and garden vegetables spring up in uncultivated soils, the plants revert to the likeness of the original wild stock; but Dr. Hooker observes that this is not strictly true. 'They degenerate and sometimes die out; sometimes they become stunted, and so far resemble their wild progenitors, but they

* Fauna Boreali Americana, p. 273. † Darwin 'On Variation,' chap. iii.

do not revert to the original type. Thus the Scotch kail and Brussels sprouts, if neglected, become as unlike the wild *Brassica Oleracea* as they are unlike one another; and our finer kind of apples, if grown from seed, degenerate and become crabs, but in so doing, they become crab states of the varieties to which they belong, and do not revert to the original wild crab-apple; and the same is true to a great extent of cultivated roses, and of the raspberry, strawberry, and most garden fruits.'* This experienced botanist therefore concludes that the characters of a variety are never so entirely obliterated that it has no longer a claim to be considered a variety.

How far do domestic races differ from wild species in their capacity to interbreed?—Hybridisation of animals and plants.—It is now time to return to a question which was mooted at the commencement of this chapter, namely, the freedom with which all artificially produced races breed together, and how far this clearly constitutes a real difference between them and the most closely allied wild species.

There are no less than 288 wild species of the pigeon family (*Columbidæ*†;) yet, although some of these approach very near to others in their characters, they will not, so far as experiments have yet been tried, pair together, presenting in this respect a marked contrast to those domestic races which, as before stated (p. 290), would, if found wild, have been ranked by ornithologists as true species, yet which pair freely and produce fertile offspring.

All the different races of domestic dogs breed together, and John Hunter's opinion has already been cited, that the jackal and wolf must be classed as of the same species, because when crossed they produce fertile mules. A capability of thus breeding together has often been proposed, as the best practical test of a real distinctness of species. The experiment with which we are most familiar relates to the mixed offspring of the horse and the ass; and in this case it is well established that the he-mule can generate and the she-mule produce. Such cases occur in Spain and Italy, and

* Hooker, 'Flora of Australia,' p. ix.

† C. L. Bonaparte, cited by Darwin, 'On Variation,' p. 133.

much more frequently in the West Indies and New Holland; but these mules seldom breed in warm countries, still more rarely in temperate regions, and never in cold climates; and no instance is known of two such mules, male and female, having bred together.

The hybrid offspring of the she-ass and the stallion, the *γίννος* of Aristotle, and the hinnus of Pliny, differs from the mule, or the offspring of the ass and mare. In both cases, says Buffon, these animals retain more of the dam than of the sire, not only in the magnitude, but in the figure of the body; whereas, in the form of the head, limbs, and tail, they bear a greater resemblance to the sire. It seems rarely to happen that any hybrids are truly intermediate in character between the two parents. Thus Hunter mentions that, in his experiments with the dog and the wolf, one of the hybrid pups resembled the wolf much more than did the rest of the litter, and we are informed by Wiegmann, that, in a litter obtained in the Royal Menagerie at Berlin, from a white pointer and a she-wolf, two of the cubs resembled the common wolf-dog, but the third was like a pointer with hanging ears.

The phenomena of hybridity in plants present a remarkable parallel to those in the animal kingdom; and we have learnt more from the cultivators of plants, because they have been able to conduct their experiments on a grander scale, sowing great numbers of the two species which they desire to cross, and taking small account of failures, provided that some of the results of crossing are successful.

The first accurate experiments in illustration of this curious subject appear to have been made by Kölreuter, who obtained a hybrid from two species of tobacco, *Nicotiana rustica* and *N. paniculata*, which differ greatly in the shape of their leaves, the colour of the corolla, and the height of the stem. The stigma of a plant of *N. rustica* was fertilised with the pollen of a plant of *N. paniculata*. The seed ripened, and produced a hybrid which was intermediate between the two parents, and which, like all the hybrids which this botanist brought up, had imperfect stamens. He afterwards impregnated this hybrid with the pollen of *N. paniculata*, and

obtained plants which much more resembled the last. This he continued through several generations, until, by due perseverance, he actually changed the *Nicotiana rustica* into the *Nicotiana paniculata*.

The plan of crossing adopted was the cutting off of the anthers of the plant intended for fructification before they had shed pollen, and then laying on foreign pollen upon the stigma. The same experiment has since been repeated with success by Wiegmann, who found that he could bring back the hybrids to the exact likeness of either parent, by crossing them a sufficient number of times with individuals of one of the pure stocks.

The blending of the characters of parent stocks, in many other of Wiegmann's experiments, was complete; the colour and shape of the leaves and flowers, and even the scent, being often intermediate. An intermarriage, also, between the common onion and the leek (*Allium cepa* and *A. porrum*) gave a mule plant, which, in the character of its leaves and flowers, approached most nearly to the garden onion, but had the elongated bulbous root and smell of the leek.

The same botanist remarks, that vegetable hybrids, when not strictly intermediate, more frequently approach the female than the male parent species; *but they never exhibit characters foreign to both.* A re-cross with one of the original stocks generally causes the mule plant to revert towards that stock; but this is not always the case, the offspring sometimes continuing to exhibit the character of a full hybrid.

Gärtner, in his work on the hybridisation of plants, has shown that some pure species which can be united with unusual facility will produce sterile hybrids, while others which are crossed rarely, or with extreme difficulty, produce hybrids which are very fertile, as for example in different species of the genus *Dianthus* or pink. The same botanist repeatedly crossed the common red and blue pimpernels, *Anagallis arvensis* and *A. cœrulea*, which, says Darwin, the best naturalists rank as mere varieties of one species, and found them absolutely sterile. These plants, besides their distinctness in colour, differ slightly in the nervation of their leaves and in the shape of their petals; and botanists who

attach importance to the test of sterility conclude that they are specifically distinct, although scarcely any of them would have come to such an opinion before the experiment of crossing had been tried.

Wiegmann diversified as much as possible his mode of bringing about these irregular unions among plants. He often sowed parallel rows, near to each other, of the species from which he desired to breed; and, instead of mutilating, after Kölreuter's fashion, the plants of one of the parent stocks, he merely washed the pollen off their anthers. The branches of the plants in each row were then gently bent towards each other and intertwined; so that the wind, and numerous insects, as they passed from the flowers of one to those of the other species, carried the pollen and produced fecundation.

When we consider how busily many insects are engaged in conveying anther-dust from flower to flower, especially bees, flower-eating beetles, and the like, it seems a most enigmatical problem how it can happen that promiscuous alliances between distinct species are not perpetually occurring.

How continually do we observe the bees diligently employed in collecting on their hind legs the red and yellow powder with which the stamens of flowers are covered, and, after passing from one flower to another, carrying it to their hive for the purpose of feeding their young! In thus providing for their own progeny, these insects assist materially the process of fructification.* Few persons need be reminded that the stamens in certain plants grow on different blossoms from the pistils; and, unless the summit of the pistil be touched with the fertilising dust, the fruit does not swell, nor the seed arrive at maturity. It is by the help of bees, moths, and other insects, that the development of the fruit of many such species is secured, the powder which they have collected from the stamens being unconsciously left by them in visiting the pistils.

A vast amount of plants are hermaphrodite, yet Mr. Darwin, following up the views suggested by Andrew Knight,

* See Barton 'On Geography of Plants,' p. 67.

has proved experimentally that even with such plants the intermarriage of two separate individuals gives more vigour and fertility to the offspring than if the female organs are fertilised by the pollen of males of the same individual. The whole arrangement of the flower may seem to be made for the purpose of close interbreeding, and yet insects and other means are employed by nature for crossing the hermaphrodite with another individual of the same species.

How often, during the heat of a summer's day, do we see the males of diœcious plants, such as the yew-tree, standing separate from the females, and sending off into the air, upon the slightest breath of wind, clouds of buoyant pollen! That the zephyr should so rarely intervene to fecundate the plants of one species with the anther-dust of others, seems almost to realise the converse of the miracle believed in by the credulous herdsmen of the Lusitanian mares—

> Ore omnes versæ in Zephyrum, stant rupibus altis
> Exceptantque leves auras: et sæpe sine ullis
> Conjugiis, vento gravidæ, mirabile dictu.*

Mr. Darwin has discovered that when a flower is fertilised by the wind, it never has a gaily coloured corolla; but when its fertilisation depends on the aid of insects, the flowers are conspicuous in colour and size, evidently in order to attract their observation.†

When we consider the facility with which the skilful gardener produces hybrid races, it seems strange that we do not oftener meet with hybrids in a state of nature. But it must be remembered that the conditions in the two cases are very different.

The stigma imbibes, slowly and reluctantly, the granules of the pollen of another species, even when it is abundantly covered with it; and if it happen that, during this period ever so slight a quantity of the anther-dust of its own species alight upon it, this is instantly absorbed, and the effect of the foreign pollen destroyed. Besides, it does not often happen that the male and female organs of fructification, in different species, arrive at a state of maturity at precisely the same

* Georg. lib. iii. 273. † Origin of Species, 4th edition, p. 239.

time. Even where such synchronism does prevail, so that a cross impregnation is effected, the chances are very numerous against the establishment of a hybrid race.

The greater part even of those seeds of wild plants which are well ripened are either eaten by insects, birds, and other animals, or decay for want of room and opportunity to germinate. Unhealthy plants are the first which are cut off by causes prejudicial to the species, being usually stifled by more vigorous individuals of their own kind. If, therefore, the relative fecundity or hardiness of hybrids be in the least degree inferior, they cannot maintain their footing for many generations in a wild state. In the universal struggle for existence, the right of the strongest must eventually prevail; and the strength and durability of a race depend in a great degree on its prolificness, in which hybrids are acknowledged to be generally deficient.

It is admitted on all hands, that in proportion as the species of animals and plants are remote from each other in structure they are averse to sexual union; and that species which the zoologist and botanist would usually class as distinct most commonly refuse to unite, and if they can be crossed and produce offspring, the hybrids are sterile. Whenever we find that two races regarded by many as true species will produce fertile hybrids, we are reduced to the dilemma of choosing between two alternatives; either to reject the test of hybridity, or to declare that the two species, from the union of which the fruitful progeny has sprung, were mere varieties. If we prefer the latter, we are compelled to question the reality of the distinctness of all other supposed species which differ no more than the parents of such prolific hybrids; for although we may not be enabled immediately to procure, in all such instances, a fruitful offspring, yet experiments show that sometimes, after repeated failures, the union of two recognised species may at last, under very favourable circumstances, give birth to a fertile progeny.

Two kinds of pheasant, our common species, *Phasianus colchicus*, and *P. torquatus*, breed together, and the hybrids

are perfectly fertile.* The two pimpernels, as before stated (p. 309), cannot be crossed.

Tendency of different races of domestic cattle and sheep to herd apart.—Although more than one species of wolf as well as the jackal have been crossed with the dog (see p. 294), and this mixture is supposed to have contributed somewhat to the great diversity of our artificial breeds, yet these same wolves and the jackal keep distinct in a wild state. So also more than one of the aboriginal races or sub-species of European wild cattle, which kept distinct in prehistoric times, have now been blended and confounded together, and even the humped cattle of India have been crossed with our domestic varieties and have produced fertile offspring. Two species of wild pig, as before stated, the European *Sus scrofa* and the *Sus Indica*, have also been confounded together in some of our domestic races. Yet there is every reason to believe that such mixtures would not have occurred in a state of nature. This may be explained simply by the preference which animals exhibit to unite with others of the same race rather than with those which differ considerably from them.

In Paraguay the horses have much freedom, and those of the native race of the same colour and size prefer associating together rather than with imported horses. Three distinct sub-races of the horse in Circassia, whilst living nearly a free life, refrain almost always from crossing. It has been observed, in a district stocked with heavy Lincolnshire and light Norfolk sheep, that both kinds will, when they are all turned out together, 'in a very short time separate to a sheep;' the Lincolnshires drawing off to the rich soil, and the Norfolks to their own dry light soil; and as long as there is plenty of grass, 'the two breeds keep themselves as distinct as rooks and pigeons. In this case different habits of life tend to keep the races distinct.'†

The origin of a new race of sheep, recorded in the Philosophical Transactions for 1813, also illustrates the disposition of even closely related varieties to herd apart, and has also been cited by Professor Huxley as proving the strong

* Origin of Species, 4th edition, p. 300.

† Darwin 'On Variation,' chap. xvi. p. 102, who cites Marshall.

tendency which there is in a newly arisen variety to be perpetuated. 'A farmer in Massachusetts possessed a flock of fifteen ewes and a ram of the ordinary kind. In the year 1791 one of the ewes presented her owner with a male lamb, differing from its parents by a proportionally long body and short bandy legs, whence it was unable to emulate its relatives in those sportive leaps over the neighbouring fences, in which they were in the habit of indulging much to the good farmer's vexation. His neighbours imagined that it would be an excellent thing if all his sheep were endued with the stay-at-home tendencies enforced by nature upon the newly arrived ram, and they advised Wright to kill the old patriarch of his fold and instal the "otter," or "Ancon" ram in his place. The result justified their sagacious anticipations. Young lambs were almost always pure Ancons or pure ordinary sheep, and when sufficient Ancon sheep were obtained to interbreed with one another, it was found that the offspring was always pure Ancon. In this well-authenticated instance we have a distinct race established at once or by a leap, and that race breeding true. When the Ancon sheep were herded with other sheep they kept together, so that it was believed that this breed might have been indefinitely protracted, had it not been superseded by the introduction of the Merino sheep, which were not only superior to the Ancons in wool and meat, but were equally quiet and orderly.'*

Pallas on domesticity eliminating sterility. Correlation of growth.—Pallas has remarked that domesticity eliminates the tendency to sterility which belongs to nearly allied species in a state of nature. As bearing on this subject, Mr. Darwin observes that there are many animals which, when tamed or subjugated to man, refuse to breed in captivity, although they enjoy perfect health, as the tiger, for example, in India, and parrots in Europe, and the elephant except when allowed, as in Assam, to range in a half-wild state in the woods; a fact showing how easily sterility may be superinduced when habits long fixed, as well as many of the

* Huxley, Westminster Review, 1860. Article on Darwin 'On the Origin of Species.'

conditions of existence in a wild state, are interfered with. But those species which more readily accommodate themselves to new circumstances arising out of their association with man, and which can be carried by him to all climates, exhibit the same plasticity of character in reference to the reproductive organs.

It cannot, however, be pretended that a satisfactory explanation can be offered of the tendency of domestication to increase the prolificness of animals and plants. In reference to the opposite effect of a return to the wild state, the following fact is worthy of mention. About the year 1419 some rabbits were introduced into Porto Santo, one of the Madeira islands, where they multiplied exceedingly, and have flourished ever since in a feral state. In many of their characters they constitute a marked race, which is smaller than the original parent stock. When two of the males were brought to the London Zoological Gardens, they refused to pair with any varieties of domestic rabbits, isolation for many generations under peculiar geographical conditions having apparently superinduced an aversion to cross even with such nearly allied races.

If two wild species, such as the wolf and the jackal, can by the intervention of man be made to breed together and the offspring proves fertile, such a result must shake our faith in the theory that species have been specially endowed with mutual sterility in order to keep them distinct. It is certainly very strange that when domesticated races have been made to differ to such an extent that if wild they would have been referred by naturalists to different genera, there should still be scarcely any well-attested examples even of an approach to sterility in their mongrel offspring. It is all the more strange if we are persuaded of the truth of Mr. Darwin's view, that the whole organisation of an animal is so tied together, that when even slight variations occur in any one part other parts usually become modified.

Among many other illustrations which he gives of this principle, called by him in the 'Origin of Species' 'correlation of growth,' and in his last work 'correlated variability,' he mentions that pigeons with feathered feet have skin

between their outer toes, pigeons with short beaks have small feet, and those with long beaks large feet; and some instances of correlation, he remarks, are quite whimsical: thus, cats which are entirely white and have blue eyes are generally deaf. One case is recorded where the blue iris at the end of four months began to grow dark-coloured, and then the cat began to hear.*

If the sterility of the mule offspring be due, as the same naturalist suggests, to the imperfection of their reproductive organs arising from the blending together of two different structures and constitutions, which causes a disturbance and interferes with the development of the embryo, we might have expected that differences affecting permanently not only the external form and shape, but even the shape of the skull in many vertebrate animals, as well as their instincts and habits, would have been accompanied, when such fixed varieties were crossed, with a disturbance in the reproductive organs and consequent sterility in the hybrids.

At the same time we must remember that the greatest changes in races have been brought about by selection, and it has never been the object of man to modify the reproductive organs with a view of producing two races mutually sterile, nor, if he wished to make such an experiment, would he know in what manner to proceed. Moreover, we have seen how possible it is to alter the foliage of plants without their seeds varying, or to change their seeds, fruit, or flowers without the character of the root or leaves being affected. It is in fact established, in spite of 'correlation,' that we may cause some organs to be greatly modified, while another to which we have not directed our attention may continue almost or entirely unaltered. In the next chapter, when we treat of Natural Selection, we shall have again to consider in what way the varieties of wild species may be supposed to have departed so far in the course of ages from the parent stock and from each other as to be incapable of being crossed, notwithstanding the fact which seems directly opposed to such a result, that a slight amount of variation in individuals of the same species when they are intermarried infuses fresh vigour and increased fertility into the offspring.

* Dr. Sichet, cited by Darwin 'On Variation,' p. 329.

CHAPTER XXXVII.

NATURAL SELECTION.

NATURAL AS COMPARED TO ARTIFICIAL SELECTION—TENDENCY IN EACH SPECIES TO MULTIPLY BEYOND THE MEANS OF SUBSISTENCE—TERMS 'SELECTION' AND 'SURVIVAL OF THE FITTEST'—GREAT NUMBER AND VARIETY OF THE NATURAL CONDITIONS OF EXISTENCE ON WHICH THE CONSTANCY OR VARIATION OF A SPECIES DEPENDS—ACCLIMATISATION OF SPECIES—THE INTERCROSSING OF SLIGHT VARIETIES BENEFICIAL—BREEDING IN AND IN INJURIOUS—WILD HYBRID PLANTS, AND OPINIONS OF LINNÆUS ON PROTEAN GENERA—DE CANDOLLE ON WILD HYBRIDS—HYBRIDITY WILL NOT ACCOUNT FOR SPECIAL INSTINCTS—THE SPECIES OF POLYMORPHOUS GENERA MORE VARIABLE AND COMPARATIVELY MODERN—ALTERNATE GENERATION DOES NOT EXPLAIN THE ORIGIN OF NEW SPECIES.

Natural as compared to artificial selection.—In the last chapter we have spoken of the great changes which man has brought about in the course of many generations in the form and characters of animals and plants, by selecting certain useful varieties of a species, and breeding from them to the exclusion of other varieties less profitable or pleasing to him. In this way he has gone on accumulating differences in successive generations until new races have been formed as distinct in outward shape, and sometimes in the internal structure of important organs, as are most of the species which we meet with in nature; the races, however, thus artificially produced being distinguishable from wild species by the fertility of the offspring produced by their union.

We may next consider the modification of species effected by variation and what Mr. Darwin has called 'natural selection,' of which we gave a brief analysis in Chap. xxxv. How far do the breeder, the agriculturist, and gardener, when they form new races, simply imitate a process by which, in a much greater lapse of time, nature causes still more important deviations from the original type?

Of the laws which may govern variation we are, as Mr. Darwin admits, profoundly ignorant; and if, as seems probable, these laws embrace the principle of progressive development explained in the first volume (Chap. IX.), they must be of so high and transcendental a nature that we may well despair of ever gaining more than a dim insight into them. But granting what is undeniable, that there is a tendency in all animals and plants to possess individual peculiarities by which they differ slightly from their parents and from each other, are there not forces in operation in the organic and inorganic world, which, in the course of thousands or millions of generations, may cause new races, varying more and more in a particular direction, until at length they constitute new species? If there be such a process in nature, it will most nearly resemble that kind of human selection which has been called 'unconscious,' and which for reasons explained in the last chapter is even more effective in the long run than that which is intentional.

Tendency in each species to multiply beyond the means of subsistence.—It has already been stated that if all the progeny of each animal and plant which are born into the world were allowed to come to maturity, a single species would soon fill the whole of the habitable land or water. Malthus long ago pointed out, that in the case of man, if his capability of increase were not checked by scarcity of food, the earth would soon fail to afford standing-room for the descendants of a single pair. The elephant, says Darwin, although reckoned the slowest breeder of all known animals, would nevertheless so multiply, if we assume that it only begins to have young when thirty years old, and brings forth three pair between that age and the age of ninety, that if all its descendants were to live out the term of their natural life, at the end of five centuries there would be fifteen million elephants descended from a single pair.

In the severe struggle for existence which is always going on, those varieties of species which have any even the slightest advantage over others inhabiting the same district will be the survivors. They may be able to bear a degree of

cold or heat, moisture or dryness, which others cannot endure; they may have strength or agility to escape foes to which others must fall victims; but the great trial, as before hinted, consists in the capacity of maintaining their ground at that season of the year when food is scarcest.

'*Natural Selection*' *or* '*Survival of the fittest.*'—Mr. Herbert Spencer has proposed to substitute for 'Natural Selection' the term 'Survival of the fittest;'* an expression which is often very appropriate, and which some naturalists prefer, because the various causes which in the natural world enable one variety or race to prevail over another, act according to fixed laws, and do not imply a conscious choice like the selection of the breeder. But the metaphor employed by Darwin appears to me legitimate and often useful, as reminding us of the close analogy which exists between the manner in which new races are formed by man and the way in which it is supposed by Darwin and Wallace that they are slowly produced by nature. Professor Huxley in his comments on this subject observes, that the winds and waves of the Bay of Biscay in the district called the Landes near Bordeaux have spread out over a wide area great heaps of sand all the grains of which are below a certain size. These grains have been separated from the larger gravel with as much precision as if by the aid of a sieve. That which the wind and the sea are to a sandy beach the sum of all the influences which we term the conditions of existence is to living organisms. The weak are sifted out from the strong. A frosty night selects the hardy plants in a plantation from among the tender ones as effectually as if the intelligence of a gardener had been operative in cutting the weaker organisms down.†

If the reader will reflect on the changes in the earth's physical geography and climate which were alluded to in the first volume (Chapters xi. and xii.), as having occurred in the course of geological periods, he will not fail to perceive that the new conditions to which plants and animals inhabiting any given province must be exposed will be far more important in the aggregate than the change of circumstances to

* Principles of Biology, 444.

† Nat. Hist. Rev., Vol. IV., p. 578, 'On Origin of Species.'

which man can in a few thousand years subject any animal or plant under domestication.

Were we to attempt to enumerate all the conditions which Mr. Herbert Spencer has concisely termed the 'environment' of a species, they would be almost endless. They would comprise not only the mean temperature of the air or water, but the extreme heat or cold in the different seasons of the year, the quantity and intensity of sunshine at different periods, the number of clear and of rainy days, the quantity of ice and snow, the direction and strength of the wind, the pressure of the atmosphere and its electrical state, the nature of the soil, its elevation above the sea, the habits, instincts, and properties of hundreds of contemporary animals and plants, some of them friendly, others inimical, the comparative abundance or rarity of those species on which the food of a given animal or plant may depend—circumstances, many of them, wholly beyond the control of the breeder or horticulturist. All of them, moreover, are brought into play by natural selection with a uniformity and persistency which man cannot emulate.

Dr. Hooker ascertained that the average range in vertical height of flowering plants in the Himalayan mountains amounted to 4,000 feet, and the upper and lower limits of some species are even distant from each other as much as 8,000 feet. If we transplant individuals which inhabit the higher limits in these mountains into our British gardens, we find that they are hardier, and better able to stand the cooler climate of England, than those taken from the inferior or warmer stations. This acclimatisation has been the result of natural selection during thousands of generations. The physiological constitution of the plant has been acted upon, and a hardy race established, although the change may not have been sufficient to cause it to rank as more than a variety. It may sometimes be more dwarfed in size than individuals of the same species living in the moist and hotter region far below. It may perhaps vary slightly in the colour of its flowers, and, if deciduous, in the period of shedding its leaves or in its general habits of growth. Yet its characters may not be on the whole sufficiently distinct to induce the botanist to rank it as

more than what is called a geographical variety. In arriving at such an opinion he may perhaps be chiefly guided by his ability to trace in the individuals inhabiting all the intermediate heights a gradual passage from one extreme of the series to another.

Intercrossing of slight varieties beneficial.—It would be an interesting experiment, and one which has not yet been made, to cross individuals taken from the lowest station with those hardier races which have been formed by acclimatisation in the upper regions of the mountain, and ascertain whether they would produce as much seed as individuals fertilised by the pollen of plants of the same station. If there were any signs of comparative sterility in such crosses. is would afford an indication of the commencement under nature of that character which distinguishes wild species from artificially formed races. There is good reason, however, to believe that before any difficulty of crossing, or any deficiency of prolific power in the offspring, would be apparent, the races must depart so widely from each other that their distinctness as species would already be a debateable question with the naturalist. And this brings us to the principal obstacle which we encounter when we endeavour to refer the gradual formation of a new species to variation and natural selection. If some degree of sterility was found in the offspring of slight varieties, and this want of prolific power went on augmenting in proportion as the deviation from a common stock became more and more marked, the fact that closely allied species inhabiting the same region keep distinct would be intelligible. But the phenomena are precisely the reverse. Instead of any reluctance being exhibited by slight variations to intermarry and propagate their kind, their intermixture, on the contrary, takes place freely and infuses fresh vigour and fertility into the species. Individuals of the normal type are always the most numerous, and slight varieties are usually soon merged in the general average, so that the new characters disappear. In some cases where the races are so wide apart as to be thought by some to belong to distinct species, it is only necessary to cross their mongrel or hybrid offspring with pure individuals of one of

the two parent stocks for six or sometimes eight generations in succession, and every trace of the foreign admixture will be lost. The mutual absorption in this manner of the European and negro races the one into the other, by a certain number of intermarriages with one of the two stocks, has been frequently verified. The efficacy of the principle above adverted to, in causing species to breed true for ages, and checking lawless divergence, in spite of the numerous varieties which occur in every generation, is obvious; the only difficulty is to conceive how, if there be such proneness in each aberrant form to merge into the normal type, a new and permanent species can ever be established. It would seem to require prolonged isolation under altered conditions, such as may occur in different parts of the same continent, or still more frequently in different islands of the same archipelago. But we have yet to learn what degree of divergence must be attained in two races sprung from the same stock before a decided disinclination to breed together will arise, and how much farther this must be carried before the offspring of the cross, if produced, will be sterile.

Breeding in and in injurious.—It has already been stated that certain domestic races prefer breeding with their own kind; while, on the other hand, it is well ascertained that too much breeding in and in has an injurious effect.

The half-wild cattle which have been kept for four or five centuries or more in British parks, as in those of Lord Tankerville and the Duke of Hamilton, where the total number varies from sixty to eighty, are relatively far less fertile than the enormous herds of half-wild cattle in South America. But even in the latter case it is believed that the occasional introduction of animals from distant localities is necessary to prevent degeneration in size and fertility.* The decrease in bulk from ancient times of the British cattle alluded to must, says Darwin, have been prodigious, as according to Rütimeyer they are the descendants of the gigantic *Bos primigenius.* The Chillingham cattle are white, but this is partly due to selection, as dark-coloured calves are

* Darwin 'On Variation,' chap. xvii., who cites Azara.

occasionally destroyed. In the Pampas, in Texas, or in Africa, where cattle have run wild in large herds, they have acquired a nearly uniform dark brownish-red.* A breed called Niatas, seen by Darwin on the banks of the Plata, has a short and broad forehead and other peculiarities in the shape of the skull and in the projection and curvature of the lower jaw. In this variety scarcely a single bone agrees exactly in shape with that of the common ox. This breed, which has existed for at least a century, is a good illustration of the manner in which a marked variety may be formed in a nearly wild state, and of the tendency of such a new race, when brought into contact with other breeds, to keep distinct. Such a tendency may point to the manner in which, in the course of many generations, if man did not interfere, a greater divergence from a common original and a more decided aversion to sexual union might be superinduced. If the lapse of time necessary for such transformations be very great, the extinction of intermediate races will take place, by which a new bar to the commingling of the nearest allied types will be raised.

In speculating on this subject, Mr. Darwin reminds us that a slight change in the conditions of life is found to be very generally advantageous to cultivated animals and plants, although we know that great changes are sometimes injurious. So, in the case of man, the invalid whose constitution will be benefited by going from England to the South of France or Madeira, may perish if transferred to Fernando Po. We may easily imagine, that, although the crossing of most of the varieties of cultivated plants and animals imparts strength and fertility to them, yet under nature, and in the course of ages, the variation may be carried so far as to modify the reproductive organs, and render the formation of a fertile hybrid germ impossible.†

The refusal of many tamed animals to breed in captivity, has been alluded to, and it demonstrates the susceptibility of the reproductive system to be affected by a change in

* Azara and others, cited by Darwin 'On Variation,' p. 86.

† Darwin 'On Variation,' chap. xviii.

the natural conditions of life. That changes greater in degree or even equal, but continuing uniformly in force for many thousands of generations, should bring about the mutual sterility of two allied races or species, is quite conceivable.

If this point of divergence had been reached by the breeder or horticulturist, the derivability of a new species by gradual deviation from an old type would almost have ceased to be a debateable question in natural history; but perhaps the tendency of varieties to keep separate is as much as we could expect to see produced in the limited time over which our observations can have extended, more especially if (as is believed by some naturalists) domestication has itself a tendency to eliminate sterility.

Allusion has been made to the extinction of intermediate varieties. This would happen the more readily on the principle well pointed out by Darwin, that in order that a given area should support the greatest number of individuals, these ought to belong to a great many widely dissimilar types; and what is true of genera, must sometimes be true of the races of a species. There may be room for those which represent the extreme terms of a series, and no equally advantageous place for those of intermediate characters.

Wild hybrid plants, and opinions of Linnæus on protean genera.—If wild species were not averse to intermarry, or if their hybrid offspring were not almost always sterile, it is obvious that in a few generations there would be a blending together of all existing types, and we should behold everywhere that state of confusion which we now only meet with in certain exceptional cases.

To the occasional occurrence of protean or polymorphous genera, as they have sometimes been called, where a great number of closely allied species occur, Linnæus makes frequent allusion in his writings. He was evidently unable to reconcile the phenomenon with his dogma of the immutability of primordially created species. In an address to the University of Upsala in 1751,* he gave a list of nearly thirty 'prolific' genera of plants, in which the species

* Linnæus, 'Plantæ Hybridæ,' 32nd Dissertation of the Amœnitates Academicæ vol. iii. p. 28–62.

were of doubtful or suspicious value; enumerating, among others, the willows and saxifrages in Europe, the oaks and asters in North America, the cactuses in South America, the heaths and everlastings at the Cape; in each of which there were so many intermediate gradations between what are commonly called allied species, as to make their origin a curious subject of enquiry. He considered how far hybridisation could explain the enigma, and having his new discovery of the sexuality of plants uppermost in his mind, he was disposed to exaggerate the extent to which that cause might have been efficacious in originating new forms. Hybrids, he says, are not always sterile, and not only species, but even genera, may have arisen from this source.* But in a great many instances, when he speaks of one species being derived from an older one, and when he calls allied species, which inhabit distant countries, 'sisters,' as being of common origin, and when he remarks of several forms that they had their first origin from one and the same source, he is evidently speculating on the origin of species by variation. In this spirit he avowedly groups many forms of *Ophrys*, *Valerianella*, *Myosotis*, *Medicago*, and other genera under single collective specific names, because, he says, after a comparison of a great number of them, all the forms will be seen to have had their origin from one source. He even throws out the idea that the day may come when botanists may hold that all the species of the same genus may have sprung from the same mother.†

The occurrence in a state of nature of some hybrids, although rare, is admitted by all botanists. *Centaurea hybrida* is produced, according to Herbert, by the frequent intermixture of two well-known species of Centaurea; but this hybrid race never seeds. *Ranunculus lacerus*, also sterile, has been produced accidentally at Grenoble, and near Paris, by the union of two ranunculi; but this occurred in gardens.‡

* 'Novas species, immo et genera ex copulâ diversarum specierum in Regno Vegetabili oriri,' etc.—Amœn. Academ. orig. ed. 1744, ed. Holm. 1749, vol. i. p. 70.

† 'Tot species dici congeneres quot eadem matre sint progenitæ.'—Amœnitates Academicæ, vol. vi. p. 12. Two eminent Swedish naturalists, Professors Fries and Lovén, have kindly pointed out to me these and many other passages in which Linnæus shows that he had freely speculated on the variability and transmutation of species.

‡ Hon. and Rev. W. Herbert, Hort. Trans., vol. iv. p. 41.

Mr. Darwin has lately (in the summer of 1867) satisfied himself by experiment that the common oxlip is a natural hybrid between the primrose and cowslip, and these two last he considers to be distinct species. Mr. Herbert, in one of his ingenious papers on mule plants, endeavours to account for their rare occurrence in a state of nature, from the circumstance that all the combinations that were likely to occur have already been made many centuries ago; but in our gardens, he says, whenever species, having a certain degree of affinity to each other, are transported from different countries, and brought for the first time into contact, they give rise to hybrid species.*

De Candolle's opinions.—Auguste De Candolle, in his Essay on Botanical Geography, published in 1820, observes that the *varieties* of plants range themselves under two general heads: those produced by external circumstances, and those formed by hybridity. After adducing various arguments to show that neither of these causes can explain the permanent diversity of plants indigenous in different regions, he says, in regard to the crossing of races, 'I can perfectly comprehend, without altogether sharing the opinion, that, where many species of the same genera occur near together, hybrid species may be formed, and I am aware that the great number of species of certain genera which are found in particular regions may be explained in this manner; but I am unable to conceive how any one can regard the same explanation as applicable to species which live naturally at great distances. If the three larches, for example, now known in the world, lived in the same localities, I might then believe that one of them was the produce of the crossing of the two others; but I never could admit that the Siberian species has been produced by the crossing of those of Europe and America. I see, then, that there exist, in organised beings, permanent differences which cannot be referred to any one of the actual causes of variation, and these differences are what constitute species.' † In this passage De Candolle assumes that the actual causes of variation have their strict and definite limits; an hypothesis

* Hon. and Rev. W. Herbert, Hort. Trans., vol. iv. p. 41.

† Essai Elémentaire, &c. 3ième partie.

which the advocates of transmutation say, and not without reason, is quite as arbitrary as the opposite or rival assumption of indefinite modifiability.

Hybridity will not account for special instincts.—As to the derivation of species in general from the mixture of a limited number of original stocks, differing widely from each other, all our experience is against such an hypothesis; for between plants or animals of very distinct genera we can obtain no cross-breeds. Nor is it easy to comprehend how species of intermediate character between two divergent types could give rise to a mongrel offspring having qualities and instincts fitting them to hold their ground in the struggle for life.

If we take some genus of insects, such as the bee, we find that each of the numerous species has some difference in its habits, its mode of collecting honey, or constructing its dwelling, or providing for its young, and other particulars. In the case of the common hive bee, the workers are described, by Kirby and Spence, as being endowed with no less than thirty distinct instincts.* So also we find that, amongst a most numerous class of spiders, there are nearly as many different modes of spinning their webs as there are species. When we recollect how complicated are the relations of these instincts with co-existing species, both of the animal and vegetable kingdoms, it is scarcely possible to imagine that a bastard race could spring from the union of these species, and retain just so much of the qualities of each parent stock as to preserve its ground in spite of the dangers which surround it.

The theory of the origin of species by variation and natural selection would be untenable, unless we could assign very different degrees of antiquity to the generic and specific types now existing. Some of them must date from remote geological periods, others must be comparatively modern. Of this last class are those forms of which the living representatives run so much the one into the other that scarcely any two naturalists can agree as to where the lines

* Intr. to Entom. vol. ii. p. 504. ed. 181

of demarcation between the species ought to be drawn. The British roses present a familiar illustration of this ambiguous state of things, Mr. Bentham making only five species of them, and Dr. Babington seventeen. Mr. Darwin sees in this abundance of closely allied species an active manufacture of new races, and a want of time since their origin to bring about the extinction of the varieties which still link together the divergent members of the series, and he remarks that the species of these polymorphous genera are unusually variable. When the reader has reflected on what will be said in Chapter XLII. on the extinction of species, he will understand why, as a general rule, there are so many missing links, and why 'protean' genera are the exception. No clue to this enigma is afforded by the hypothesis of special creation. On the other hand, if it had been found that fertile hybrids could spring from animals and plants which are remote in their organisation, the occurrence of protean genera might certainly be explained; but in that case they ought to have been universal, and the present condition of the animal and vegetable world would then be a greater mystery than ever.

Sexual selection.—A considerable number of the most striking external characters of animals are confined to one sex, such as the horns and canine tusks often found in the males only of quadrupeds, the ornamental plumes, gay colours, and musical voices of male birds, and the varied horns and excrescences of male insects. Mr. Darwin has shown that these characters are often useful to the males in their struggle for mates. Some actually fight together, and the possessor of the greatest strength and the best weapons will be the parent of the next generation; others captivate the females by their beauty or their song, and these, by obtaining the earliest and most vigorous mates, will have the most numerous and most healthy offspring. Favoured individuals will thus have an advantage in the transmission of their peculiarities; and in this manner, Mr. Darwin believes, have been produced the noble antlers of the stag, the sharp spurs of the cock, and the gorgeous train of the bird of Paradise. Sexual selection thus becomes an important supplement to

natural selection and may enable us to account for structures which could not be explained by the mere 'preservation of favourable variations in the struggle for life.'

Alternate generation.—The discovery in certain classes of invertebrate animals of what has been called 'alternate generation,' has suggested to some zoologists a possible mode by which Nature may usher abruptly into the world not only new organisms but even types of being of a higher grade than any which pre-existed in the same class. Certain sertularian polyps give birth to other polyps like themselves, and these again produce other individuals of the same form and structure, and this may continue for many generations till at last one of the series gives birth to a more highly organised creature called a Medusa. Formerly naturalists regarded this Medusa as belonging to a distinct genus or even family, of decidedly higher or more complex organisation than the Sertulariæ. If then, it is said, under a change of conditions the Sertularia and the Medusa should each of them go on for an indefinite number of generations producing, according to the ordinary rules of inheritance, offspring like themselves, we should have an example of the coming into existence of a new and higher form without the disappearance of the lower one from which it had been evolved; but, unfortunately for such speculations, nothing of the kind has ever been witnessed. The Sertularia, although it is hatched from an egg, never produces one, but simply gives birth to other polyps by what is termed internal gemmation, and when at length the male and female Medusæ, after sexual union, produce eggs from which the Sertulariæ are born, the whole cycle of changes returns into itself, just as do the metamorphoses of an insect. The same may be said of certain aphides, which, coming from an egg, give birth by gemmation to a sexual offspring, and these again to others like themselves, till at length some of their descendants produce perfect and winged males and females, from whose union eggs proceed, and then the cycle of transformation recommences.

Even if there had been any indication of the Sertularia and Medusa becoming each of them independent of the

other, this phenomenon would not afford an illustration of what is usually meant by special creation, as the new form would still be evolved out of the older one by descent. In truth there are only as yet two rival hypotheses, between which we have our choice in regard to the origin of species —namely, first, that of special creation—and, secondly, that of creation by variation and natural selection. In the next four chapters I shall treat of the light thrown by the geographical distribution of animals and plants on the claims of these two rival hypotheses to our acceptance.

CHAPTER XXXVIII.

ON THE GEOGRAPHICAL DISTRIBUTION OF SPECIES.

GEOGRAPHICAL DISTRIBUTION OF ANIMALS—BUFFON ON SPECIFIC DISTINCTNESS OF QUADRUPEDS OF THE OLD AND NEW WORLDS—DOCTRINE OF 'NATURAL BARRIERS'—AUSTRALIAN MARSUPIALS—GEOGRAPHICAL RELATION OF EXTINCT FOSSIL FORMS TO THEIR NEAREST ALLIED LIVING GENERA AND SPECIES—GEOGRAPHICAL PROVINCES OF BIRDS ACCORDING TO DR. SCLATER—THEIR APPLICABILITY TO ANIMALS AND PLANTS GENERALLY—NEOTROPICAL REGION—NEOARCTIC—PALÆARCTIC—ETHIOPIAN—INDIAN—AUSTRALIAN—WALLACE ON THE LIMITS OF THE INDIAN AND AUSTRALIAN REGIONS IN THE MALAY ARCHIPELAGO.

Geographical distribution of animals.—Although in speculating on 'philosophical possibilities,' said Buffon, writing in 1755, 'the same temperature might have been expected, all other circumstances being equal, to produce the same beings in different parts of the globe, both in the animal and vegetable kingdoms, yet it is an undoubted fact, that when America was discovered, its indigenous quadrupeds were all dissimilar to those previously known in the Old World. The elephant, the rhinoceros, the hippopotamus, the camelopard, the camel, the dromedary, the buffalo, the horse, the ass, the lion, the tiger, the apes, the baboons, and a number of other mammalia, were nowhere to be met with on the new continent; while in the old, the American species, of the same great class, were nowhere to be seen—the tapir, the lama, the pecari, the jaguar, the couguar, the agouti, the paca, the coati, and the sloth.'

These phenomena, although few in number relatively to the whole animate creation, were so striking and so positive in their nature, that the great French naturalist caught sight at once of a general law in the geographical distribution of organic beings, namely, the limitation of groups of distinct species to regions separated from the rest of the globe by certain natural barriers. It was, therefore, in a truly philo-

sophical spirit that, relying on the clearness of the evidence obtained respecting the larger quadrupeds, he ventured to call in question the identifications announced by some contemporary naturalists of species of animals said to be common to the southern extremities of America and Africa.*

In order to appreciate the importance and novelty of the doctrine, that separate areas of land and water were the abode of distinct species of animals and plants, we must look back to the times of Buffon, and see in what crude conjectures even so great a naturalist as his illustrious contemporary Linnæus indulged, when speculating on the manner in which the earth may first have become peopled with its present inhabitants. The habitable world was imagined by the Swedish philosopher to have been for a certain time limited to one small tract, the only portion of the earth's surface that was as yet laid bare by the subsidence of the primæval ocean. In this fertile spot the originals of all the species of plants which exist on this globe were congregated together with the first ancestors of all animals and of the human race. 'In quâ commodè habitaverint animalia omnia, et vegetabilia lætè germinaverint.' In order to accommodate the various habits of so many creatures, and to provide a diversity of climate suited to their several natures, the tract in which the creation took place was supposed to have been situated in some warm region of the earth, but to have contained a lofty mountain range, on the heights and in the declivities of which were to be found all temperatures and every climate, from that of the torrid to that of the frozen zone.† There are still perhaps some geologists who adhere to a notion once very popular, that there are signs of a universal ocean at a remote period after the planet had become the abode of living creatures. But few will now deny that the proportion of sea and land approached very nearly to that now established long before the present species of plants and animals had come into being.

The reader must bear in mind that the language of Buffon,

* Buffon, vol. v. 1755.—On the Virginian Opossum.

† 'De terrâ habitabili incremento;' also Prichard, Phys. Hist. of Mankind, vol. i. p. 17, where the hypotheses of different naturalists are enumerated.

in 1755, respecting 'natural barriers' which has since been so popular, would be wholly without meaning had not the geographical distribution of organic beings led naturalists to adopt very generally the doctrine of specific centres, or, in other words, to believe that each species, whether of plant or animal, originated in a single birthplace. Reject this view, and the fact that not a single native quadruped is common to Australia, the Cape of Good Hope, and South America, can in no way be explained by adverting to the wide extent of intervening ocean, or to the sterile deserts, or the great heat or cold of the climates, through which each species must have passed, before it could migrate from one of those distant regions to another. It might fairly be asked of one who talked of impassable barriers, why the same kangaroos, rhinoceroses, or lamas, should not have been created simultaneously in Australia, Africa, and South America? The horse, the ox, and the dog, although foreign tc these countries, until introduced by man, are now able to support themselves there in a wild state; and we can scarcely doubt that many of the quadrupeds at present peculiar to Australia, Africa, and South America, might have continued in like manner to inhabit all the three continents, had they been indigenous in each, or could they once have got a footing there as new colonists.

We have seen in the passage already cited that Buffon called attention to the fact that the apes and baboons of the Old World were nowhere to be found in America. Now that so many new forms of quadrumana have been brought to light in both continents, the want of agreement in the anatomical and many other characters of the two groups has been rendered even still more prominent.

The Old-World apes and monkeys have been called Catarrhini because they have a narrow division between the nostrils; those of the New World, Platyrrhini because their nostrils are widely separated. In the Catarrhine division the number of teeth, not only in the Orangs and Gibbons which approach nearest to the human race in form and structure, but in all the other quadrumana with the exception of one or two aberrant groups such as the Lemurs, are 32, as

in man, whereas in all the Platyrrhine monkeys they are 36, for they have four additional false molars. This marked distinction in their dentition is accompanied by many other differences; such as the prehensile tails belonging exclusively to so many of the American monkeys, and the cheek-pouches peculiar to the Old-World quadrumana.

Australian marsupials.—The adherence to certain peculiar types of structure observable in the animals inhabiting distinct geographical provinces was illustrated in a still more striking manner, some time after the publication of Buffon's great work, by the discovery in Australia of a group of mammalia so unlike those of the Old World as to be referable even to a distinct sub-class called the Marsupial, of which there was only one genus previously known on the globe, namely, the Opossum (*Didelphis*) of America. Some of these pouched animals, like the kangaroo, were herbivorous, others, like the Tasmanian wolf (*Thylacinus*), carnivorous, and on the whole they presented a parallel series in which were found representatives of nearly all the grand divisions of the placental mammalia of the rest of the world. Mr. Waterhouse has described about 140 species proper to the mainland of Australia, and about 9 others inhabiting New Guinea and some neighbouring islands of the Malay Archipelago. Among these, only one species, the flying opossum (*Petaurus ariel*), is common to one of the islands and the continent.

Geographical relation of extinct fossil forms to the nearest allied living genera and species.—When we speculate on the meaning of this restriction of a peculiar division of the vertebrata to a single province of the land, and try, by aid of it, to gain some insight as to the plan which Nature has followed in peopling the earth with new species, we find ourselves in some degree precluded from attributing the peculiarity of the fauna to the nature of the climate, soil, and vegetation of Australia. It has at least been ascertained experimentally that when placental mammalia of various orders, whether herbivorous or carnivorous—such as the ox, the horse, the dog, and the cat—run wild in Australia, they are not only a match for the native animals, but often obtain a mastery over them and multiply greatly at their expense. How, then, does

it happen that the marsupials ever became dominant and gained so complete an ascendency over the placentals in the struggle for life? The answer seems to be, that the more highly organised placentals were never able to gain access to Australia, since it emerged from beneath the sea. It is certain that the marsupial fauna of that continent is of great antiquity, for when we examine the bone-caves and superficial alluvium of that part of the world, we find in them, as in formations of corresponding age in Europe, the remains of extinct quadrupeds; but, instead of being referable to the placental class, as in the Old World, the Australian fossils consist of lost species of kangaroo, wombat, thylacine, and other marsupials. One of these, the *Diprotodon* of Owen, allied to the kangaroo, is of the size of a large rhinoceros; another, *Nototherium* of Owen, not much inferior in bulk. They are associated with extinct species of *Dasyurus*, besides many of smaller dimensions, such as Phalangers and Potoroos.

In like manner, when we turn to the geological records of South America, we find among the fossil remains of an age immediately antecedent to the present, entombed in cavern and alluvial deposits, the skeletons of Megatherium, Megalonyx, Glyptodon, Mylodon, Toxodon, and Macrauchenia, extinct forms generically allied to the existing sloth, armadillo, cavy, capybara, and lama. In the caves also of Brazil, we meet with extinct monkeys associated with the above, and they are referable to the genera Cebus and Callithrix, both belonging to the Platyrrhine or New-World type of quadrumana before mentioned. Thirdly, if we turn to the Europæo-Asiatic and African province—a region which comprises Europe, Asia, and the north of Africa—geology teaches us, in like manner, that where the rein-deer, musk-ox, elephant, rhinoceros, hippopotamus, horse, and many other Old-World types now prevail, there also extinct species of the same genera abounded formerly at a very modern geological period. In the present state of science we cannot speak of the fossil quadrumana of the same great province, because the Pliocene mammalia of tropical regions have as yet been so imperfectly investigated, and it is only within the tropics that the ape and monkey tribe is at present met

with. But it is worthy of notice that the extinct fossil monkeys which have been discovered in Europe and India, all of them of Miocene age, are referable to Old-World forms or to the Catarrhine division, such as the Semnopithecus and the Gibbons.

Professor Owen and Mr. Darwin have dwelt emphatically on this manifest relationship between the living and the dead—between peculiar genera and families of mammalia now inhabiting certain parts of the world and the fossil representatives of the same families found in corresponding regions.*

No hypothesis, therefore, respecting the origin of species will be satisfactory which does not render some account of the two classes of phenomena already alluded to in this chapter. First, species, and often genera and still larger groups, have such a range in space as implies that they have spread in all directions from a limited area called a 'centre of creation,' until their progress was stopped by some natural barriers, or conditions in the organic and inorganic world, hostile to their farther extension. Secondly, the restriction of peculiar generic forms to certain parts of the globe is not confined to the present period, but may be traced back to an antecedent geological epoch, when most of the species of mammalia were different from those now living. The significance of this last-mentioned fact can hardly be overrated. If we find Latin inscriptions of ancient date most common in the country where Italian is now spoken, Greek inscriptions most abundant where they now talk modern Greek, and Egyptian hieroglyphics inscribed on ancient monuments where for centuries after the Christian era the kindred Coptic tongue was still in use, we recognise at once that there is a geographical connection between the three dead and the three living or modern languages, which, even if the entire intervening history of those countries were lost, could not be questioned. In this case it would afford a powerful argument in favour of the derivative origin of the three modern languages, each of them having a nearer relationship to one of the extinct tongues than to any other lost

* Owen, British Mammals and Birds; and Darwin, Journal of South America.

forms of speech known to us by tradition or history as having been used elsewhere on the globe. So the intimate connection between the geographical distribution of the fossil and recent forms of mammalia points to the theory (without absolutely demonstrating its truth) that the existing species of animals and plants, like the above-mentioned modern forms of speech, are of derivative origin and not primordial or independent creations.

Geographical provinces of animals.—It has been ascertained that the sea as well as the land may be divided into what have been called distinct provinces, each inhabited by certain species of animals and plants, there being a considerable coincidence in the range of species in the two grand divisions of the organic world. The six principal regions sketched out in 1857 by Dr. Sclater for birds (referring rather to the genera and families in the class Aves than to the species),* are applicable, with some slight exceptions, to quadrupeds, reptiles, insects, and landshells, and to a great extent even to plants. The regions alluded to are as follows:—1. The Neotropical, comprising South America, Mexico, and the West Indies. 2. The Neoarctic, including the rest of America. 3. The Palæarctic, composed of Europe, Northern Asia as far as Japan, and Africa north of the Sahara. 4. The Ethiopian, which contains the rest of Africa and Madagascar. 5. The Indian, containing Southern Asia and the western half of the Malay Archipelago. 6. The Australian, which comprises the eastern half of the Malay islands, Australia, and most of the Pacific islands.

Some modifications of this arrangement have been since proposed. Mr. Andrew Murray, in his 'Geographical Distribution of Mammalia,' unites the Ethiopian and Indian regions, and divides North America between the Palæarctic and Neotropical regions, thus reducing the principal divisions to three. Professor Huxley † makes two primary divisions, Arctogæa and Notogæa, the latter comprising the Neotropical and Australian regions, the former the rest of the globe. Yet although there is still some difference of opinion as to

* Paper read to Linnæan Society, June, 1857.

† Proc. Zool. Soc. 1868, p. 294.

which are primary and which secondary divisions, and as to where the boundary between some of them is to be drawn, Dr. Sclater's regions are generally admitted to be natural ones, and are, in the present state of our knowledge, the best that can be used to illustrate the problems of the geographical distribution of animals.

Neotropical region.—To begin with the Neotropical, comprehending the West Indies and South America. The bird fauna of this division is, according to Dr. Sclater, the richest and most peculiar on the globe, and the mammalia are, as Buffon remarked, singularly unlike those of the Old World. I have already spoken of the Platyrrhine monkeys of South America, as well as of the sloths and armadilloes of that country, and I might add the vampires or true blood-sucking bats (*Phyllostomidæ*), also the capybara, the largest of the rodents, the carnivorous coati-mondi (*Nasua*), with a great many other forms.

If there be any truth in the theory which refers the origin of species to variation or gradual transmutation, we should expect that South America would contain a terrestrial fauna very distinct from that of other lands; for we are taught by geology that the present continents and oceanic basins are of very high antiquity,* and the southern part of the American continent is separated by a wide expanse of sea from Africa, Asia, and the land of the Antarctic regions. We cannot suppose South America to have had a free land communication with any other of the great continents in the Pliocene or scarcely perhaps in the Miocene epoch; so that even the genera of quadrupeds in Europe must have changed several times, while this Neotropical region has continued almost as isolated as it is now.

In Peru and Chili, says Humboldt, the region of the grasses is inhabited at an elevation of from 12,300 to 15,400 feet by crowds of lama, guanaco, and alpaca. These quadrupeds, which here represent the genus camel of the ancient continent, have not extended themselves either to Brazil or Mexico, because, during their journey, they must necessarily have descended into regions that were too hot for them.†

* See above, Vol. I. p. 253. † Description of the Equatorial Regions: 1814.

In this passage, published in 1814, it will be seen that already the doctrine of specific centres was tacitly assumed.

I have already stated that extinct genera of the lama, sloth, armadillo, and many other families of South American quadrupeds, have been found in the same region in a fossil state. But it is remarkable that, in some points, the fossil fuana is not so unlike that of the rest of the world as is the recent. A species of horse, for example, has been found fossil in the Pampas, and of elephant (*Mastodon Andium*) in the mountains of Peru. So also the horse, mastodon, and Siberian mammoth occur fossil throughout a considerable area in North America, although there were no representatives of any of these genera extant in the New World when it was first colonised by Europeans.

The former wide range of these quadrupeds implies a migration of Old-World forms into the New World, perhaps by way of the Andes, in Pliocene times; but how this invasion was brought about, and by what causes the Old-World species were again exterminated, we cannot conjecture. It may, however, be affirmed that we are by no means entitled, in the present state of our knowledge, to wonder at the extinction of any species. A small insect, which lays its eggs in the navels of horses, cattle, and dogs, when first born, makes it impossible, says Darwin, for any of these animals to run wild in Paraguay;* and we are extremely ignorant as to the various animals and plants, on the co-existence of which the well-being of any one species may depend.

Besides, as geologists, we must remember that the horse tribe and the elephants have been waning groups since the Miocene and Pliocene periods in the northern hemisphere. In northern India alone, the fossil remains of the Sewâlik hills have shown us that there were in the Upper Miocene period no less than seven distinct species of proboscidians of the genera *Elephas*, *Mastodon*, and *Stegodon* (as defined by Falconer), and besides these several species of mastodon flourished contemporaneously in Europe. There are now only two living representatives of the whole group, viz. *Elephas*

* Darwin, 'Origin of Species,' 4th edition, p. 83.

Indicus and *E. Africanus.* In like manner no less than twelve equine species, referred by Leidy to seven genera, have been already detected in the Pliocene and Post-Pliocene formations of the United States, no one of which survived in America at the time when it was first visited by Europeans.*

It has been objected that the insect fauna of Chili, although to a great extent peculiar to South Temperate America, contains also many generic forms of butterflies and beetles, such as Colias, Carabus and others, which are common to the northern hemisphere, and are not found in the intermediate tropical region. These insects, however, may well be supposed to have passed from north to south along the higher region of the Andes, during the cold of the Glacial period; and almost all of them seem to have been so modified in their character, that the allied forms of the north and south are not specifically identical. As to the marsupial opossums of America having Australian affinities, it has been justly remarked by Mr. Wallace that as the genus Didelphis existed in Europe in the Eocene and Lower Miocene periods, the American species are much more likely to have been derived from that source, assuming the origin of species by variation, than from Australia, where the genus in question has not hitherto been met with, either in a fossil or living state.

In this great province, the Neotropical, as indeed in every other to which we shall afterwards allude, the larger part of the species are separable from each other by lines of demarcation, whether in the animal or vegetable kingdoms, sufficiently clear to enable naturalists to agree for the most part in their systems of classification; but exceptions could be given in every great division, whether of the vertebrate or invertebrate class, where species occur which pass one into the other by so many intermediate gradations that scarcely any two naturalists take exactly the same views as to their relationship. Thus, for example, Mr. Bates observed in the valley of the Amazons swarms of a gregarious species of

* See Leidy and Hayden on Nebraska Fossil Remains, Proc. of Acad. Nat. Sci. Philadelp. 1858, p. 89.

butterfly of the elegant genus *Heliconius*, which is peculiar to tropical America. It abounds in the shades of the forest, presenting clusters of allied species and varieties, as well as some better marked forms. A conspicuous member of the group is *H. Melpomene* of Linnæus, which is found throughout Guiana, Venezuela, and parts of New Granada. It is very common at Obydos on the north side of the Amazons, and reappears on the south side of the river, in the dry forests behind Santarem. But it is absent from other parts of the valley, where a nearly allied species, *H. Thelxiope*, of the same size and shape, but differing in colour, takes its place. Both species have the same habits, and they have always been considered by entomologists as specifically distinct; but Mr. Bates came to the conclusion that one was simply a modification of the other; for he found that in those forest tracts which were intermediate in character between the drier air of Obydos and the moister air of the rest of the great valley the individuals of these Heliconii were transitional forms between the two reputed species alluded to. He observed them to pass by very slight variations from one extreme to the other, and yet the inference that they were hybrids produced by the intercrossing of *H. Melpomene* and *H. Thelxiope* was not admissible; for the two butterflies were never seen to pair with each other, and the intermediate varieties are unknown in several places where the two forms come in contact. If the whole district which they inhabit is contemplated, the intermediate forms are incomparably more rare than the two extreme terms of the series, and these last must, says Mr. Bates, be treated as good and true species, because they exhibit characters usually regarded as sufficient for such a distinction, and, amongst others, an aversion to pair together. A similar course of reasoning induced the same naturalist to believe in the derivation of *H. Vesta* from *H. Melpomene*, *H. Vesta* having a very wide range, and extending into the central valleys of the Andes.

The highest class of the mammalia, or the monkeys of the same region, might afford us another equally apposite illustration. There are two distinct species of Cebus, or Capuchin monkey, the Caiarara (*C. albifrons*, Spix), and that called

Prego (*C. cirrhifer*, St. Hilaire), both found on the Amazons, which differ in form and disposition. They are not local varieties, for they sometimes co-exist in the same district. But there are so many sub-species and varieties of this same monkey in equatorial America, which spread over thousands of miles of wild country, and connect together the two forms above mentioned, that, after comparing the whole, Mr. Bates affirms that a zoologist cannot separate, by any well-defined line, the two extremes of the series.*

The naming of these varieties has often been a subject of great perplexity in the Zoological Gardens in London, and equally so in the museums at Paris, as anyone may satisfy himself by consulting the printed catalogue, drawn up by Isidore Geoffroy St. Hilaire. Nor are the Capuchins the only platyrrhine monkeys whose classification is embarrassing, as appears by the same official document. To those who adopt Mr. Darwin's views, these transitional forms are precisely what we ought to encounter, for they simply imply, as before hinted, p. 324, that some genera and species are comparatively modern, so that there has not been time for the causes of extinction to make gaps in the series of new varieties.

Neoarctic region.—We have next to pass to the Neoarctic region, extending from the centre of the table-land of Mexico to the North Pole. If we compare the southern limits of this great province with the nearest lands on the east and west, the north of Africa on the one side and China on the other, we find a complete dissimilarity between the fauna of the American and that of the African and Asiatic continents; but, the farther we go north and enter those latitudes where the three continents approach each other, the more the discordance in genera and species diminishes. It has often, indeed, been said that the whole circumpolar region forms one province; but some of the American species formerly identified with the European—the badger, for example—have been found to differ on closer examination, and the musk-ox (*Ovibos moschatus*) is peculiar to America, although the same

* Bates, Naturalist on the Amazons, vol. ii. p. 101.

animal formerly ranged, as we know from its fossil remains, over Germany, France, and England.

The predominant influence of climate over all the other causes which limit the range of species in the mammalia is perhaps nowhere so conspicuously displayed as in the region now under consideration. It will be observed that on this continent between the Rocky Mountains and the Atlantic there are no great geographical barriers running east and west, such as high snow-clad mountains, barren deserts, or wide arms of the sea, capable of checking the free migration of species from north to south. Yet the arctic fauna, so admirably described by Sir John Richardson, has scarcely any species in common with the fauna of the State of New York, which is 600 miles farther south, and comprises about forty distinct mammifers. If again we travel farther south about 600 miles, and enter another zone, running east and west, in South Carolina, Georgia, Alabama, and the contiguous States, we again meet with a new assemblage of land quadrupeds, and this again differs from the fauna of Texas farther to the south, where frosts are unknown. But notwithstanding the distinctness of those zones of indigenous mammalia, there are some species, such as the buffalo (*Bison Americanus*), the racoon (*Procyon lotor*), and the Virginian opossum (*Didelphis Virginiana*), which have a wider habitation, ranging almost from Canada to the Gulf of Mexico; but they form exceptions to the general rule. The opossum of Texas (*Didelphis cancrivora*) is different from that of Virginia, and other species of the same genus are found westward of the Rocky Mountains, in California, for example, where almost all the mammalia differ specifically from those in the United States.

Palæarctic region.—We next come to the third or Palæarctic region, comprising Europe and Northern Asia as far as Japan, and also including Africa north of the desert of the Sahara. Selecting our examples here, as before, chiefly from the mammalia, we may first mention the extraordinary range from east to west of the European species of quadrupeds; for no less than 44 of these, out of 58, are common to Europe and Amoorland, or that part of North-eastern Asia which lies between latitude 45° and 55° north. In the same group

there are some species which have not so wide a range east and west, but which extend for great distances in a north and south direction. Thus the tailless hare, or *Pica*, passes far into the Arctic latitudes, and the tiger, *Felis Tigris*, into the tropical, even as far south as Java.

The propriety of considering Morocco, Algeria, and Tunis as part of the same province as Europe and Northern Asia, has been questioned, but only with reference to the mammals; for the birds, reptiles, insects, and plants are all decidedly of Palæarctic forms. As to the mammalia, Mr. Wallace has given a table showing that no less than thirty-three of the Algerian species are absolutely identical with European or West-Asiatic quadrupeds; fourteen more are representatives of European *genera*, and ten belong to *genera* of Western Asia and Siberia. But, on the other hand, seven or eight species have been supposed to give an Ethiopian or extra-European character to the North-African highlands. They are all desert-haunting species—an antelope, a monkey (*Macacus Inuus*), the same as that which inhabits the rock of Gibraltar, a lion, leopard, cerval, and hunting leopard. These same large feline species range through the whole of Africa from the Mediterranean to the Cape, and may, says Mr. Wallace, very probably have crossed the desert in the tracks of caravans. If we confine our attention to the genera instead of species, we find that out of thirty-one only three are common to the Palæarctic and Ethiopian regions.

From what we have said in the first volume (p. 497) of the submarine ridge between Gibraltar and the nearest part of Africa or Tangiers (a ridge twenty-two miles long and from five to seven miles broad, and nowhere covered by a depth of water exceeding 220 fathoms), we learn that the union of Southern Europe with Africa does not imply a great change in the relative level of land and sea. The geologist at least is familiar with the fact that the rising and sinking of land and of the bed of the Mediterranean within the newer Pliocene period has, in Sicily and elsewhere, far exceeded the amount which would be required to unite the coasts on the opposite sides of the Straits of Gibraltar. A change of level of about 70 fathoms would

unite Malta and Gozo with Sicily, and one of 200 fathoms would join Malta to Tripoli by an isthmus 170 miles long. A similar change would connect Italy with Sicily, and the latter with Africa by the Adventure Bank. We can only explain, by this and other analogous land communications of modern geological date, the remarkable resemblance of the fauna and flora of the islands of the Mediterranean and of the nearest mainland, notwithstanding the general depth of that sea. Some of the mountainous islands, it is true, of the Egean are inhabited by peculiar species of landshells, as was ascertained by the late Edward Forbes and Captain Spratt; but these mountains may perhaps have been insulated from a remote period, as freshwater strata of Miocene age occur in parts of them, and the surrounding sea is of vast depth. The remains of the African elephant and of the *Elephas antiquus*, and of an extinct hippopotamus in Sicily, and, what is more wonderful, of several species of elephant, and an hippopotamus in caverns in the small island of Malta, bear testimony to great geographical changes in comparatively modern or Pliocene times.

As to the distinctness above alluded to of the North-African fauna from that south of the Sahara, we know that the Great Desert was submerged beneath the sea in the Pliocene period; so that assuming that species have only one birthplace, we can account for their distinctness in these two regions, which were separated first by a barrier of water and afterwards by one of sand.

The geographical distribution of reptiles agrees as a general rule with that of the mammalia and birds; but a discrepancy has been pointed out in the Palæarctic region. Although the batrachians of Japan are all Palæarctic, the snakes agree in genera and species with those of the more southern parts of Asia or the Indian region, which we shall have presently to consider. Mr. Wallace suggests the following explanation of this apparent anomaly: he reminds us that Dr. Günther has shown that snakes are a preeminently tropical group, decreasing rapidly in the temperate regions, and absolutely ceasing at 62° N., whereas the batrachians are almost as largely developed in northern

as in tropical latitudes, being able to support the most intense cold.* We may therefore suppose Japan to have once formed a part of Northern Asia, with which it is even now almost connected by two chains of islands; in which case it might have received its birds, mammals, and batrachians from the Palæarctic region, whereas it could have derived but few or no snakes from the same quarter, since the great cold extends to a much lower latitude in Eastern Asia than in Western Europe. If at a subsequent period Japan became connected with Southern Asia through the Loo-choo and Majicosima islands, it might then have been colonised by snakes of Indian origin, which would easily establish themselves in a region unoccupied by any representatives of the same class. Batrachians, on the contrary, as well as the birds and mammals of Southern Asia, would find a firmly established Palæarctic population ready to resist the invasion of all intruders.†

Ethiopian region.—The next or fourth zoological province is the Ethiopian, including Africa south of the Great Desert, and the island of Madagascar. That this part of Africa should be characterised by a peculiar indigenous fauna is a fact in perfect accordance with Buffon's theory of natural barriers.

We have already stated that the sea even in Post-Tertiary times covered the space now occupied by the Sahara, so that Africa was for vast periods surrounded by water on every side but the north-east, where it was connected by an isthmus with Asia. Such a connection might explain why there are some few species, such as the lion, dromedary, and jackal, common to Africa and Asia, and also why many Asiatic genera are represented by allied African species. The elephant, for example, of Africa, though so nearly resembling that of India, is distinct, being smaller, having a rounder head and larger ears than the Indian one, and having only three instead of four toes on each hind foot. There are three African species of rhinoceros, all differing from the three Indian ones. The genus hippopotamus is now represented by two species

* Günther on Geographical Distribution of Snakes, Proc. Zool. Soc. 1858, p. 374.

† Wallace on Zoological and Botanical Geography, Nat. Hist. Rev. 1864, p. 114.

exclusively African, although it occurred in India in the Miocene period, and in Europe in the Pliocene and Post-Pliocene. Also the giraffe, the gorilla, the chimpanzee, the blue-faced baboon, the four-fingered monkey (*Colobus*), and many carnivora, such as *Proteles*, allied to the hyæna. In proportion as we advance towards the southern part of the Ethiopian region we find in the temperate zone other forms, many of them agreeing generically with those inhabiting the zone of corresponding climate north of the equator in Asia. Among these are the quagga and the zebra; answering to the horse, the ass, and the jiggetai of temperate Asia. Among pachydermatous animals the hyrax is peculiar, among the ruminantia the Cape buffalo and many antelopes, such as the springbok, the oryx, the gnu, the leucophoë, the pygarga, and several others.

Separated from Africa by the Mozambique channel, which is 300 miles wide, Madagascar, with two or three small islands in its immediate vicinity, forms a zoological sub-province, of which all the species except one, and nearly all the genera, are peculiar. The one exception alluded to consists of a small insectivorous quadruped (*Centetes*), found also in the Mauritius, to which place, however, it is supposed to have been taken in ships. The most characteristic feature of this remarkable fauna consists in the number of quadrumana of the Lemur family, no less than six genera of those monkeys being exclusively met with in this island, and a seventh genus of the same, called *Galago*, which alone has any foreign representative, being found, as we might from analogy have anticipated, on the nearest mainland. Madagascar is nearly as large as Great Britain, and being in the same latitude as the adjoining part of the continent of Africa, enjoys a similar climate. Had the species of quadrupeds in Madagascar agreed with those of Africa, as do those of England with the rest of Europe, the naturalist would have inferred that there had been a land communication since the period of the coming in of the existing quadrupeds, whereas we may now conclude that the broad Mozambique channel has constituted an insuperable barrier to the fusion of the continental fauna with that of the great island during the whole

period that has elapsed since the living species of mammalia came into being.

The period when Madagascar was united to some part of Africa was probably as remote as the Upper Miocene era, at which time we know that the outline of the land in Europe varied materially from that which it now exhibits; so that we may readily suppose the arm of the sea constituting the Mozambique channel to have been dry land at that period. Some of the peculiar Miocene genera may have survived on the island after they became extinct on the continent, and a still greater number of species. Other families, such as the Lemurs, may have multiplied more in the island than on the continent; but in spite of such changes the two faunas continental and insular (assuming the origin of species by variation and natural selection) would continue to bear the mark of having sprung from a common source at a comparatively modern era. They would continue to have more affinity with each other than with any more distant region, such as the Indian or Australian. On the other hand, the hypothesis of special creation helps us in no way to account for such generic and family ties as bind together these two sets of animals in each of which all the species are distinct.

Indian region.—We have next to consider the Indian region, comprising Southern Asia and the western half of the Malay Archipelago. Its boundary on the side of Arabia has not yet been well defined, as that country seems at present to be regarded by zoologists as debateable ground between the Ethiopian, Indian, and Palæarctic regions. Although the Indian species are very distinct from those of Africa, a great many of the genera of quadrupeds are common to both continents. There are, however, some forms which are peculiar to the Indian region; such as the sloth-bear (*Prochilus*), the musk-deer (*Moscus*), the nylghau, the gibbon or long-armed ape, and some others.

The elephant and tapir of Sumatra and Borneo are the same as the Indian species, and the rhinoceros of Sumatra and that of Java are each of them respectively common to Bengal and Malacca. One of the gibbons or long-armed apes (*Hylobates leuciscus*) is common to the Malay peninsula and the

islands of Java and Borneo, though wanting in Sumatra. The wild ox of Java also occurs on the Asiatic continent. None of these large animals, says Mr. Wallace, could possibly have passed over the arms of the sea which now separate these countries; so that they point clearly to the existence of a land communication between the islands and the mainland since the origin of such mammalia.

Between 80 and 90 mammals inhabit Java, and nearly as many occur in Sumatra; more than half of these species are common to the two islands. Borneo, which is much less explored, has yielded already upwards of 60 species, and more than half of these are not met with either in Java or Sumatra. As each island contains not only many species but some genera peculiar to itself, the date of their former union can only be spoken of as modern when we understand the term in a geological sense. We may feel sure, for example, that it occurred during some part of the Pliocene epoch; and this speculation is rendered the more probable by the fact that a difference of level of 50 fathoms, or only 300 feet, would unite Borneo, Java, and Sumatra with the mainland, or with Malacca and Siam,* and a rise of 100 fathoms would include the Philippine Islands and Bali or the whole of the Indian region (see map, fig. 138). To this question of a modern geographical change we shall again refer.

In regard to the birds of the mainland, the genus *Euplocamus* of the pheasant family affords a good illustration of a variable form. Thus *E. melanotus*, or black-backed kalige of Sikkim, is found to pass by numerous varieties in the intermediate Aracan country into the *E. lineatus*, of Tenasserim and Pegu. The varieties are considered by Dr. Sclater not to be hybrid forms.

Australian region—and Mr. Wallace on the boundary between it and the Indian region in the Malay Archipelago.—Lastly, we come to the sixth or Australian region, which, as we have before mentioned, is inhabited by mammalia belonging almost exclusively to the marsupial sub-class. The only associated and indigenous placental species are a few rodents and bats. Although the mainland of Australia is very isolated, yet when the

* Wallace, Geog. Soc. Journ. 1864, and Malay Archipelago, Vol. I. p. 17.

whole geological province is considered, there seems at first sight to be no natural barrier sufficiently strong in a north-west direction to account for the marked line of separation in the islands of the Malay Archipelago between the species belonging to the Australian and those proper to the Indian region.

Fig. 138.

Map showing the boundaries of two great zoological provinces, the Indian and the Australian, as defined by Alfred R. Wallace, Esq. The lands which are shaded belong to the Australian, the unshaded to the Indian region.

a b. Line exceeding 100 fathoms in depth separating the Indian and Australian zoological regions.

c b. Boundary line between the Malayan and Papuan races, showing their near coincidence with the range of species of the inferior animals (see Chap. XLIII.)

The geographical distribution of the two faunas, which are remarkably distinct, is shown in the annexed map, all the lands which are shaded belonging to the Australian and those which are unshaded to the Indian region. Mr. Wallace has also pointed out that the line *a b*, which divides two different assemblages of mammalia and birds, coincides very nearly with

the line *c b*, which divides two of the best characterised races of mankind, the Malayan and the Pacific, in which last are included the Papuans, Australians, and Polynesians.*

The Straits of Lombok, through which the line *a b* passes between the island of that name and Bali, are only fifteen miles across, less wide than the Straits of Dover, and yet the contrast between the animals of various classes on both sides of this narrow channel is as great as that between those of the Old and New Worlds. In other words, the discordance, not only in species but in genera, equals that which is usually caused by a wide ocean rather than by straits which allow of one shore being easily seen from the other. It has already been stated (p. 349) that all those islands of the Malay Archipelago which are only separated from the mainland of Asia by a depth of water of less than 100 fathoms contain a fauna which is strictly Indian. Mr. Wallace, in commenting on this fact, has pointed out the obvious relation of the present distribution of animals and plants to changes in the position of land and sea, which must be assumed to have taken place in comparatively modern times.

The reader has already been told (Chapters XII., XIV., and XXXI.) of the elevation and depression of the crust of the earth and the conversion of land into sea and sea into land, with which geology has made us acquainted, and of the accompanying fluctuations in the state of the organic world. Taking these for granted, we may expect to find proofs that some islands were once united with each other or with the neighbouring continents at comparatively recent periods. Where this has happened, the same species of animals and plants will be found to be common to the lands now disjoined, and the seas which divide them will usually be shallow. But if the natural productions are dissimilar, we may safely speculate on the separation having taken place at a more remote epoch, as in the case before mentioned of Madagascar and Africa, where we have seen that the intervening sea is very deep.

The line *a b* in the map, fig. 138, indicates a line of sounding exceeding 100 fathoms, the sea to the westward of this

* See below, Chap. XLIII.

line having everywhere a depth of less than 100 fathoms; and here we find the limits of the two faunas, the Indian and the Australian, very sharply defined. When speaking of the contrast of the animals inhabiting the two regions, Mr. Wallace says: 'In Australia there are no apes or monkeys, no cats or tigers; no wolves, bears, or hyænas; no deer, or sheep, or oxen; no elephant, horse, squirrel, or rabbit; none, in short, of those familiar types of quadrupeds which are met with on the Indian area. Instead of these Australia has its marsupials, kangaroos, opossums, and wombats, and the representatives of a still lower division of the mammalia, the duck-billed Platypus (or Ornithorynchus), and the Echidna. Its birds,' he continues, 'are almost as peculiar: it has no woodpeckers and no pheasants, families which exist in every other part of the world. But instead of them it has the mound-making brush-turkeys, the honeysuckers, the cockatoos, and the brush-tongued Lories, which are found nowhere else upon the globe.'*

If we cross the straits from Lombok to Bali, which we may do in two hours, we find on the western side a complete contrast in animal life. We meet, for example, with barbets, fruit-thrushes, and woodpeckers; instead of honeysuckers and brush-turkeys. In like manner, if we travel from Java or from Borneo, and pass over to Celebes, the Moluccas, and New Guinea, the difference is almost equally striking. In Java or Borneo the forests abound in monkeys of many kinds, and wild cats, deer, civets, otters, and squirrels are constantly met with. In Celebes or the Moluccas, none of these occur, but the prehensile-tailed opossum is the terrestrial animal most seen. Some pigs, however, and deer of Indian types, probably introduced by man, are met with.

Mr. Wallace moreover reminds us that the diversity in the natural productions of the two great regions does not correspond to any of the physical or climatal divisions of the surface. On both sides of the line of demarcation we find in the same latitude islands of volcanic origin similar in soil, elevation, moisture, dryness, and fertility, and equally covered

* Wallace, Journal of Geographical Society, 1864, and Malay Archipelago, Vol. I., p. 21.

with forests. How then are we to explain the distinctness of the two faunas? The greater depth of the sea which separates the lands east of the line *a b* (fig. 138) from those to the west of it would lead us to speculate on a longer period of separation. Still it may be asked, how is it possible to conceive that a channel in one place only fifteen miles wide should have been so effective in arresting the migration of species from one region into the other? Before we give an account of Mr. Wallace's speculations on this head, we must state, that marked as is the contrast on the opposite sides of the line *a b*, some colonisation from one province to the other has already begun, although less perhaps than along any one of the points of contact of the five great zoological provinces before described. In Lombok there are several mammalia of the placental class. The largest of them is the ape called *Macacus cynomolgus*. As to the wild pig, it may have been introduced by man, and the same may be said of the Moluccan deer, which occurs in the island of Timor. The *Paradoxurus musanga* of the weasel tribe, also found in many of these islands east of the line *a b*, is an animal often domesticated. But a shrew-mouse and a feline animal, *Felis megalotus*, peculiar to Timor, are less easily explained; unless, indeed, our acquaintance with the mammalia of Java is still defective, a supposition by no means improbable. The squirrels extend from Lombok eastward as far as Sumbawa, but no farther.

In the case of Borneo and Celebes there seems to have been a partial fusion of the mammalia at some remote period, as there is a species of baboon, a wild cat, and a squirrel in Celebes, all belonging to Indian *genera*; but that so few of the mammals of Borneo should have reached Celebes, and that there should be hardly a land-bird in common and very few insects, is, perhaps, says Mr. Wallace, even more extraordinary than the distinctness of the fauna of Bali and Lombok; for the two latter islands being wholly of volcanic origin, may be comparatively modern, whereas Borneo and Celebes must from their great size and altitude be very ancient. Between the latter also, although the sea is much wider than in the Straits of Lombok, there is a

great extent of opposing coasts which would be very favourable to mutual immigration.

It is a singular fact that there are distinct species of wild pig in almost every large island, as in Sumatra, Borneo, Java, New Guinea, and Timor, and one or more other species are said to inhabit Gilolo. Some of these may have been introduced by man at so remote a period as to have varied greatly from the parent stock; for if the prevailing opinion be correct, that the Japanese pigs, of which specimens were lately exhibited at the Zoological Gardens, be mere varieties of the domesticated *Sus Indica*, we may imagine a little more divergence to be sufficient to constitute a true species. We shall see in the next chapter, p. 358, that pigs have been known, when swept by a flood into the sea, to swim for great distances, so that some of them may have passed in this manner from island to island.

That so few quadrupeds, birds, and insects have obtained a footing on the opposite sides of such channels as those of Lombok or the Macassar Straits, seems the more strange, when we reflect on well-known instances of birds even of weak flight having sometimes been carried by the wind during heavy gales over wide spaces of sea. But the power of preoccupancy is great in enabling the old indigenous inhabitants to prevent stray individuals of foreign species from effecting a permanent settlement. As to the Straits of Lombok, they are very narrow, but there is so rapid a marine current always running through them, that it might easily prevent quadrupeds and reptiles from swimming across from shore to shore.

To assist us in accounting for the marked separation between the Indian and Australian faunas, as well as for many partial exceptions to the distinctness of the two groups of animals in some of the islands of the Malay Archipelago, Mr. Wallace has suggested an imaginary parallel, of which I can only give a brief outline. Suppose the bed of the Atlantic to be gradually converted into land, partly by the deposition of large bodies of sediment poured down by rivers, and partly by slow upheaval and volcanic action. Let the two continents of Africa and America be

thus more and more extended, so that the ocean, which now separates them, should at last be reduced to an arm of the sea a few hundred miles wide. Let us, at the same time, imagine several islands to be upheaved in mid-channel, and that, while the subterranean forces varied in intensity and shifted their points of greatest action, these islands became sometimes connected with the main-land on one side of the strait, and sometimes with the land on the other side. Two or more of the islands also might occasionally be joined together and then broken up again, till at last, after many ages of such intermittent action, with many a long intervening period of comparative tranquillity, we might have an irregular archipelago of islands filling up the ocean channel of the Atlantic, in whose appearance and arrangement we could discover nothing to tell us which had been connected with Africa and which with America. But the animals and plants inhabiting these islands would certainly reveal this portion of their former history. On those islands which had ever formed a part of the South American continent we should be certain to find such common birds as chatterers, toucans, macaws, and humming-birds, and some peculiar quadrupeds, such as spider-monkeys, pumas, tapirs, anteaters, and sloths; while, on the islands which had been separated from Africa, we should be equally sure to meet with horn-bills, orioles, and honeysuckers, and some quadrupeds contrasting strongly with those of South America, such as baboons, lions, elephants, buffaloes, and giraffes. Those intermediate islands which at different times had had a temporary connection with either continent, would contain a certain amount of mixture in their living inhabitants. Such seems to Mr. Wallace to have been the case with the islands of Celebes and the Philippines. Other islands, again, though in such close proximity as Bali and Lombok, might each exhibit an almost unmixed sample of the productions of the continents of which they had directly or indirectly once formed a part.

In the Malay Archipelago we have indications of a vast Australian continent which once reached westward to the island of Celebes, and was characterised by a very peculiar

fauna and flora; the western part of this continent was afterwards broken up gradually and irregularly into islands. At the same time Asia, which at first was separated from the Australian continent by a wide ocean, appears to have been extending its limits in a south-east direction in an unbroken mass, so as to include Sumatra, Java, and Borneo, and probably reaching as far as the present 100-fathom line of soundings, or as far as the boundary line *a b*, map, fig. 138. Afterwards the south-eastern portion of this land was separated into islands as we now see it, some of them coming into almost actual contact with the scattered fragments of the great Southern or Australian land.

There are some peculiarities in the distribution of animals and plants in oceanic islands which have a more direct and obvious bearing on the question of the origin of species by variation than the grouping of species on continental tracts. I shall therefore consider that subject in a separate chapter;* but as I shall be unable to reason on the somewhat exceptional facts which these islands present in relation to theories of the origin of species, without constantly adverting to the relative powers of migration which different species enjoy, I shall treat of this latter subject first in order, and then allude to the insular faunas and floras.

* Chapter XLI.

CHAPTER XXXIX.

ON THE MIGRATION AND DIFFUSION OF TERRESTRIAL ANIMALS.

MIGRATION OF QUADRUPEDS—MIGRATORY INSTINCTS—DRIFTING OF ANIMALS ON ICE-FLOES—MIGRATION OF BIRDS—MIGRATION OF REPTILES—INVOLUNTARY AGENCY OF MAN IN THE DISPERSION OF ANIMALS.

Migration of quadrupeds.—Before we consider the geographical distribution of aquatic animals, it may be useful to enquire what facilities the terrestrial species enjoy of spreading themselves over the surface of the earth. The tendency of each species to multiply is so great, that unless checked it would soon extend its range over as wide an area as is accessible to it. Whether it feed on plants or prey on other animals, it will not cease to enlarge the boundaries of its habitation until its progress is arrested by some rival species better fitted to the soil, climate, and organic conditions of the country; or by some lofty and unbroken chain of mountains which it cannot scale, or by a desert, or the sea, or by cold or heat, or some other barrier.

Mr. Wallace and Mr. Bates have shown that large rivers such as the Amazons and Rio Negro are capable of forming effective barriers to the farther spread of many species of monkeys. This happens even where the same kind of forest occurs on the opposite banks. Mr. Darwin also mentions that the biscacha, a rodent somewhat resembling a large rabbit, which abounds in the Pampas, although it has crossed the broader river Paranà, has never been able to extend its range across the Uruguay. Geology teaches us that the present continents have been formed by the union of large pre-existing islands; and what were formerly straits of the sea have often become, under a new arrangement of the land, broad valleys and the channels of great rivers such as the Amazons, the Orinoco, and the La Plata. It is therefore

probable that the real obstacle to the farther spread of many species is not their inability to swim over large rivers, but the pre-occupancy of the land on the farther side by an assemblage of animals fitted for all the stations which the region affords. If an intruder attempts to colonise, he is overpowered by a rival species already established in great numbers.* But for such resistance scarcely any quadrupeds would be stopped by rivers and narrow friths; for the greater part of them swim well, and few are without this power when urged by danger and pressing want. Thus, amongst beasts of prey, the tiger is seen swimming about among the islands and creeks in the delta of the Ganges, and the jaguar traverses with ease the largest streams in South America.† The bear, also, and the bison, cross the current of the Mississippi. The popular error, that the common swine cannot escape by swimming when thrown into the water, has been contradicted by several curious and well-authenticated instances during the floods in Scotland of 1829. One pig, only six months old, after having been carried down from Garmouth to the bar at the mouth of the Spey, a distance of a quarter of a mile, swam four miles eastward to Port Gordon, and landed safe. Three others, of the same age and litter, swam, at the same time, five miles to the west, and landed at Blackhill.

In an adult and wild state, these animals would doubtless have been more strong and active, and might, when hard pressed, have performed a much longer voyage, especially if aided by powerful tides and currents. Hence islands many miles distant from a continent may obtain inhabitants by casualties which, like the storms of 1829 in Morayshire, may only occur once in many centuries, or thousands of years, under all the same circumstances.

The late Edward Forbes told me that when he was on board a surveying vessel commanded by Lieutenant Graves, R.N., in the Grecian Archipelago, the sailors amused themselves with setting a terrier at a domestic pig which they had recently purchased. The animal being worried, threw

* Andrew Murray. Geographical Distribution of Mammalia, 1866, p. 18.

† Buffon, vol. v. p. 204.

himself overboard and made for the nearest land in sight, which was many miles distant. As the pig was more fit for the table than for feats of agility, and as the reputation of his tribe for swimming stood very low, the sailors were slow in getting out the boat to give chase, so that the animal having a fair start, landed soon after sunset, just as they came up to him, and further pursuit in the dark was impossible. These facts help to explain the exceptionally wide distribution of pigs already mentioned (p. 354) in the Malay Archipelago, where several distinct species are found in the Moluccas and New Guinea. The *Sus papuensis* of the latter island is the only non-marsupial terrestrial animal known to inhabit it.

The power of crossing rivers is essential to the elephant in a wild state, for the quantity of food which a herd of these animals consumes renders it necessary that they should be constantly moving from place to place. The elephant crosses the stream in two ways. If the bed of the river be hard, and the water not of too great a depth, he fords it. But when he crosses great rivers, such as the Ganges and the Niger, the elephant swims deep, so deep that the end of his trunk only is out of the water; for the complete immersion of his body is a matter of indifference to him, provided he can bring the tip of his trunk to the surface, so as to breathe the external air.

Animals of the deer kind frequently take to the water, especially in the rutting season, when the stags are seen swimming for several leagues at a time, from island to island, in search of the does, especially in the Canadian lakes; and in some countries where there are islands near the sea-shore, they fearlessly enter the sea and swim to them. In hunting excursions, in North America, the elk of that country is frequently pursued for great distances through the water.

The large herbivorous animals, which are gregarious, can never remain long in a confined region, as they consume so much vegetable food. The immense herds of bisons (*Bos Americanus*) which often, in the great valleys of the Mississippi and its tributaries, blacken the surface of the prairie lands, are continually shifting their quarters, followed by wolves,

which prowl about in their rear. 'It is no exaggeration,' says Mr. James, 'to assert, that in one place, on the banks of the Platte, at least ten thousand bisons burst on our sight in an instant. In the morning we again sought the living picture; but upon all the plain, which last evening was so teeming with noble animals, not one remained.'*

Migratory instincts.—Besides the disposition common to the individuals of every species slowly to extend their range in search of food, in proportion as their numbers augment, a migratory instinct often developes itself in an extraordinary manner, when, in consequence of an unusual number of births or of a sudden scarcity of provisions, great multitudes are threatened with famine. It may be useful to enumerate some examples of these migrations, because they may put us upon our guard against attributing a high antiquity to a particular species merely because it is diffused over a great space: they show clearly how soon, in a state of nature, any species might spread itself in every direction, from a single point, and how the territory of one animal may be invaded by another, leading occasionally to the extermination of the weaker species.

In very severe winters, great numbers of the black bears of America migrate from Canada into the United States; but in milder seasons, when they have been well fed, they remain and hybernate in the north.† The rein-deer, which in Scandinavia scarcely ever ranges to the south of the sixty-fifth parallel, descends, in consequence of the greater coldness of the climate, to the fiftieth degree in Chinese Tartary, and often roves into a country of more southern latitude than any part of England.

In Lapland, and other high latitudes, the common squirrels, whenever they are compelled, by want of provisions, to quit their usual abodes, migrate in amazing numbers, and travel directly forwards, allowing neither rocks nor forests, nor the broadest waters, to turn them from their course. In like manner the small Norway rat sometimes pursues its migrations in a straight line across rivers and lakes; and Pennant

* Expedition from Pittsburg to the Rocky Mountains, vol. ii. p. 153.

† Richardson's Fauna Boreali-Americana, p. 16.

informs us, that when the rats, in Kamtschatka, become too numerous, they gather together in the spring, and proceed in great bodies westward, swimming over the rivers, lakes, and arms of the sea. Many are drowned or destroyed by water-fowl or fish. As soon as they have crossed the river Penginsk, at the head of the gulf of the same name, they turn southward, and reach the rivers Judoma and Okotsk by the middle of July; a district more than 800 miles distant from their point of departure.

The lemings, also, a small kind of rat, are described as natives of the mountains of Kolen, in Lapland; and once

Fig. 139.

The Leming or Lapland Marmot (*Mus Lemmus*, Linn.)

or twice in a quarter of a century they appear in vast numbers, advancing along the ground and 'devouring every green thing.' Innumerable bands march from the Kolen, through Northland and Finmark, to the Western Ocean, which they immediately enter; and after swimming about for some time, perish. Other bands take their route through Swedish Lapland to the Bothnian Gulf, where they are drowned in the same manner. They are followed in their journeys by bears, wolves, and foxes, which prey upon them incessantly. They generally move in lines, which are about three feet from each other, and exactly parallel, going directly forward through rivers and lakes; and when they meet with stacks of hay or corn, gnawing their way through them instead of passing round.* These excursions usually precede a rigorous winter, of which the lemings seem in some way forewarned.

Vast troops of the wild ass, or *onager* of the ancients, which

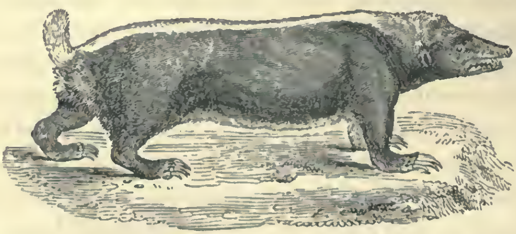
* Phil. Trans., vol. ii. p. 872.

inhabit the mountainous deserts of Great Tartary, feed, during the summer, in the tracts east and north of Lake Aral. In the autumn they collect in herds of hundreds, and even thousands, and direct their course towards the north of India, and often to Persia, to enjoy a warm retreat during winter.* Bands of two or three hundred quaggas (a species of wild ass) are sometimes seen to migrate from the tropical plains of Southern Africa to the vicinity of the Malaleveen River. During their migrations they are followed by lions, who slaughter them night by night.†

The migratory swarms of the springbok, or Cape antelope, afford another illustration of the rapidity with which a species under certain circumstances may be diffused over a continent. When the stagnant pools of the immense deserts south of the Orange River dry up, which often happens after intervals of three or four years, myriads of these animals desert the parched soil, and pour down like a deluge on the cultivated regions near the Cape. The havoc committed by them resembles that of the African locusts; and so crowded are the herds, that 'the lion has been seen to walk in the midst of the compressed phalanx with only as much room between him and his victims as the fears of those immediately around could procure by pressing outwards.'‡

Dr. Horsfield mentions a singular fact in regard to the geographical distribution of the *Mydaus meliceps*, an animal

Fig. 140.



Mydaus meliceps, or badger-headed Mydaus. Length, including the tail, 16 inches.

intermediate between the polecat and badger. It inhabits Java, and is 'confined exclusively to those mountains

* Wood's Zoography, vol. i. p. 11.

† On the authority of Mr. Campbell. Library of Entert. Know., Menageries, vol. i. p. 152.

‡ Cuvier's Animal Kingdom by Griffiths, vol. ii. p. 109. Library of Entert. Know., Menageries, vol. i. p. 336.

which have an elevation of more than 7,000 feet above the level of the ocean; and there it occurs with the same regularity as many plants. The long-extended surface of Java, abounding with isolated volcanos with conical points which exceed this elevation, affords many places favourable for its resort. On ascending these mountains, the traveller scarcely fails to meet with this animal, which, from its peculiarities, is universally known to the inhabitants of these elevated tracts, while to those of the plains it is as strange as an animal from a foreign country. In my visits to the mountainous districts, I uniformly met with it; and, as far as the information of the natives can be relied on, it is found on all the mountains.'*

Now, if asked to conjecture how the Mydaus arrived at the elevated regions of each of these isolated mountains, we might say that, before the island was peopled by man, by whom their numbers are now thinned, they may occasionally have multiplied so as to be forced to collect together and migrate: in which case, notwithstanding the slowness of their motions, some few would succeed in reaching another mountain, some twenty, or even, perhaps, fifty miles distant; for although the climate of the hot intervening plains would be unfavourable to them, they might support it for a time, and would find there abundance of insects on which they feed. Volcanic eruptions, which at different times have covered the summits of some of those lofty cones with sterile sand and ashes, may have occasionally contributed to force on these migrations.

Drifting of animals on ice-floes.—The power of the terrestrial mammalia to cross the sea is very limited, and it was before stated that the same species is scarcely ever common to districts widely separated by the ocean. If there be some exceptions to this rule, they generally admit of explanation; for there are natural means whereby some animals may be floated across the water, and the sea may, in course of ages, wear a wide passage through a neck of land, leaving individuals as a species on each side of the new channel. Polar bears are known to have been frequently drifted on the ice from Greenland to Iceland; they can also swim to considerable

* Horsfield, Zoological Researches in Java, No. ii., from which the figure is taken

distances, for Captain Parry, on the return of his ships through Barrow's Straits, met with a bear swimming in the water about midway between the shores, which were about forty miles apart, and where no ice was in sight.* 'Near the east coast of Greenland,' observes Scoresby, 'they have been seen on the ice in such quantities, that they were compared to flocks of sheep on a common; and they are often found on field-ice, above two hundred miles from the shore.'† Wolves, in the arctic regions, often venture upon the ice near the shore, for the purpose of preying upon young seals, which they surprise when asleep. When these ice-floes get detached, the wolves are often carried out to sea; and though some may be drifted to islands or continents, the greater part of them perish, and have been often heard in this situation howling dreadfully, as they die by famine.‡

During the short summer which visits Melville Island, various plants push forth their leaves and flowers the moment the snow is off the ground, and form a carpet spangled with the most lively colours. These secluded spots are reached annually by herds of musk-oxen, and rein-deer, which, migrating from the North American continent, traverse the ice for hundreds of miles to graze undisturbed on these luxuriant pastures.§ The rein-deer often pass along in the same manner, by the chain of the Aleutian Islands, from Behring's Straits to Kamtschatka, subsisting on the moss found in these islands during their passage.‖ But the musk-ox, notwithstanding its migratory habits, and its long journeys over the ice, does not exist either in Asia or Greenland.¶

On floating islands of drift-wood.—Within the tropics there are no ice floes; but, as if to compensate for that mode of transportation, there are floating islets of matted trees, which are often borne along through considerable spaces. These are sometimes seen sailing at the distance of fifty or one hundred miles from the mouth of the Ganges, with living trees standing

* Append. to Parry's Second Voyage, years 1819-20.

† Account of the Arctic Regions, vol. i. p. 518.

‡ Turton in a note to Goldsmith's Nat. Hist., vol. iii. p. 43.

§ Supplement to Parry's First Voyage of Discovery, p. 189.

‖ Godman's American Nat. Hist., vol. i. p. 22.

¶ Dr. Richardson, Brit. Assoc. Report, vol. v. p. 161.

erect upon them. The Amazons, the Orinoco, and the Congo also produce these verdant rafts, which are formed in the manner already described when speaking of the great raft of the Atchafalaya, an arm of the Mississippi, where a natural bridge of timber, ten miles long, and more than two hundred yards wide, existed for more than forty years, supporting a luxuriant vegetation, and rising and sinking with the water which flowed beneath it.

On these green islets of the Mississippi, young trees take root, and the water-lily or nenuphar displays its yellow flowers: serpents, birds, and the cayman alligator come to repose there, and all are sometimes carried to the sea, and engulphed in its waters.

Spix and Martius relate that, during their travels in Brazil, they were exposed to great danger while ascending the Amazons in a canoe, from the vast quantity of drift-wood constantly propelled against them by the current; so much so that their safety depended on the crew being always on the alert to turn aside the trunks of trees with long poles. The tops alone of some trees appeared above water, others had their roots attached to them with so much soil that they might be compared to floating islets. On these, say the travellers, we saw some very singular assemblages of animals, pursuing peacefully their uncertain way in strange companionship. On one raft were several grave-looking storks, perched by the side of a party of monkeys, who made comical gestures, and burst into loud cries, on seeing the canoe. On another was seen a number of ducks and divers, sitting by a group of squirrels. Next came down, upon the stem of a large rotten cedar-tree, an enormous crocodile, by the side of a tiger-cat, both animals regarding each other with hostility and mistrust, but the saurian being evidently most at his ease, as conscious of his superior strength.*

Similar green rafts, principally composed of canes and brushwood, are called 'camelotes' on the Paranà in South America; and they are occasionally carried down by inundations, bearing on them the tiger, cayman, squirrels, and other quadrupeds, which are said to be always terror-stricken

* Spix and Martius, Reise, &c., vol. iii. pp. 1011, 1013.

on their floating habitation. No less than four tigers (pumas) were landed in this manner in one night at Monte Video, lat. 35° S., to the great alarm of the inhabitants, who found them prowling about the streets in the morning.*

In a memoir published in the United Service Journal (No. XXIV. p. 697) a naval officer relates that, as he returned from China by the eastern passage, he fell in, among the Moluccas, with several small floating islands of this kind, covered with mangrove-trees interwoven with underwood. The trees and shrubs retained their verdure, receiving nourishment from a stratum of soil which formed a white beach round the margin of each raft, where it was exposed to the washing of the waves and the rays of the sun. The occurrence of soil in such situations may easily be explained; for all the natural bridges of timber which occasionally connect the islands of the Ganges, Mississippi, and other rivers, with their banks, are exposed to floods of water, densely charged with sediment.

The late Admiral W. H. Smyth informed me, that, when cruising in the 'Cornwallis' amidst the Philippine Islands, he saw more than once, after those dreadful hurricanes called typhoons, floating masses of wood, with trees growing upon them. Ships have sometimes been in imminent peril, as these islands were often mistaken for terra firma, when, in fact, they were in rapid motion.

It is highly interesting to trace, in imagination, the effects of the passage of these rafts from the mouth of a large river to some barren island, raised from the deep by the operations of the volcano and the earthquake. If a storm arise, and the frail vessel be wrecked, still many a bird and insect may succeed in gaining, by flight, some point on the newly-formed island, while the seeds and berries of herbs and shrubs, which fall into the waves, may be washed up on the strand. But if the surface of the deep be calm, and the raft is carried along by a current, or wafted by some slight breath of air fanning the foliage of the green trees, it may arrive, after a passage of several weeks, in some bay of the island, into which its plants and animals may be poured out as from an ark, and

* Sir W. Parish's Buenos Ayres, p. 187, and Robertson's Letters on Paraguay, p. 220.

thus a colony of several hundred new species may at once be naturalised.

Although the transportation of such rafts may be of extremely rare and accidental occurrence, and may happen only once in thousands or tens of thousands of years, they may yet account in tropical countries for the extension of some species of mammalia, birds, insects, landshells, and plants to lands which without such aid they could never have reached.

Migration of birds.—It was before stated that birds, notwithstanding their great locomotive powers, form no exception to the general rule, that groups of distinct species are circumscribed within definite limits.

In parallel zones of the northern and southern hemispheres, a great general correspondence of form is observable, both in the aquatic and terrestrial birds; but there is rarely any specific identity: and this phenomenon is remarkable, when we consider the readiness with which some birds, not gifted with great powers of flight, shift their quarters to different regions, and the facility with which others, possessing great strength of wing, perform their aërial voyages. Many species migrate periodically from high latitudes, to avoid the cold of winter, and the accompaniments of cold,—scarcity of insects and vegetable food. For this purpose, they often traverse the ocean for thousands of miles, and recross it at other periods, with equal security.

Periodical migrations, no less regular, are mentioned by Humboldt, of many American water-fowl, from one part of the tropics to another, in a zone where there is the same temperature throughout the year. Immense flights of ducks leave the valley of the Orinoco, when the increasing depth of its waters and the flooding of its shores prevent them from catching fish, insects, and aquatic worms. They then betake themselves to the Rio Negro and the Amazons, having passed from the eighth and third degrees of north latitude to the first and fourth of south latitude, directing their course south-south-east. In September, when the Orinoco decreases and re-enters its channels, these birds return northwards.*

The insectivorous swallows which visit our island would

* Voyage aux Régions Equinoxiales, tom. vii. p. 429.

perish during winter, if they did not annually repair to warmer climes. It is supposed that in these aërial excursions the average rapidity of their flight is not less than fifty miles an hour; so that, when aided by the wind, they soon reach warmer latitudes. Spallanzani calculated that the swallow can fly at the rate of ninety-two miles an hour, the rapidity of the swift being much greater.* Bachman says that the hawk, wild pigeon (*Columba migratoria*), and several species of wild ducks, in North America, fly at the rate of forty miles an hour, or nearly a thousand miles in twenty-four hours.†

It is well known that many European birds are carried every winter during violent gales of wind from Europe to the Azores. Some of them are supposed to be blown from Great Britain to those islands.‡ In performing such flights no great exertion of muscular power may be required, if they have simply to extend their wings and allow themselves to be carried through the air in the direction of the wind. If they advance at the rate even of twenty miles an hour, they would reach the islands in forty-eight hours, a period not exceeding that during which many birds can sustain life without food (see below, p. 418).

When we reflect how easily different species, in a great lapse of ages, may be each overtaken by gales and hurricanes, and, abandoning themselves to the tempest, be scattered at random through various regions of the earth's surface, where the temperature of the atmosphere, the vegetation, and the animal productions might be suited to their wants, we shall be prepared to find some species capriciously distributed, and to be sometimes unable to determine the native countries of each. Admiral Smyth, when engaged in his survey of the Mediterranean, encountered a gale in the Gulf of Lyons, at the distance of between twenty and thirty leagues from the coast of France, which bore along many land-birds of various species, some of which alighted on the ship, while others were thrown with violence against the sails. In this manner islands may become tenanted by species of birds inhabiting the nearest mainland.

* Fleming, Phil. Zool., vol. ii. p. 43.

† Silliman's Amer. Journ. No. 61, p. 83.

‡ Mr. F. Du Cane Godman, Ibis, vol. ii. 1866, New Series.

Migration of reptiles.—Turtles migrate in large droves from one part of the ocean to another during the ovipositing season; and they find their way annually to the island of Ascension, from which the nearest land is about 800 miles distant. Dr. Fleming mentions, that an individual of the hawk's bill turtle (*Chelonia imbricata*), so common in the American seas, has been taken at Papa Stour, one of the West Zetland Islands;* and, according to Sibbald, 'the same animal came into Orkney.' Another was taken, in 1774, in the Severn, according to Turton. Two instances, also, of the occurrence of the leathern tortoise (*C. coriacea*), on the coast of Cornwall, in 1756, are mentioned by Borlase. These animals of more southern seas can be considered only as stragglers attracted to our shores during uncommonly warm seasons by an abundant supply of food, or carried by the Gulf-stream, or driven by storms to high latitudes.

Some of the smaller reptiles lay their eggs on aquatic plants; and these may often be borne rapidly by rivers, and thus conveyed to distant regions.

But that even the larger ophidians may be transported across the seas, is evident from the following most interesting account of the arrival of one at the island of St. Vincent. It is worthy of being recorded, says Mr. Guilding, 'that a noble specimen of the *Boa constrictor* was lately conveyed to us by the currents, twisted round the trunk of a large sound cedar-tree, which had probably been washed out of the bank by the floods of some great South-American river, while its huge folds hung on the branches, as it waited for its prey. The monster was fortunately destroyed after killing a few sheep, and his skeleton now hangs before me in my study, putting me in mind how much reason I might have had for fear in my future rambles through the forests of St. Vincent, had this formidable reptile been a pregnant female, and escaped to a safe retreat.' †

Involuntary agency of man in the dispersion of animals.—In a future chapter I shall speak of the transportation by man to distant regions of quadrupeds and birds which are useful

* Brit. Animals, p. 149, who cites Sibbald.

† Zool. Journ. vol. iii. p. 406. Dec. 1827.

to him, and of the effect of such colonisation in limiting the range and sometimes extirpating indigenous species of plants and animals. I shall merely consider in this place the involuntary or unintentional aid which we frequently lend to the dissemination of species, many of them not only unserviceable, but noxious and injurious to us.

Thus we have introduced the rat, which was not indigenous in the New World, into all parts of America. It has been conveyed over in ships, and now infests a great multitude of islands and parts of that continent. In like manner the Norway rat (*Mus decumanus*) has been imported into England, where it plunders our property in ships and houses.

Among birds, the house-sparrow may be cited as a species known to have extended its range with the tillage of the soil. During the last century it has spread gradually over Asiatic Russia towards the north and east, always following the progress of cultivation. It made its first appearance on the Irtisch in Tobolsk, soon after the Russians had ploughed the land. It came in 1735 up the Obi to Beresow, and four years after to Naryn, about fifteen degrees of longitude farther east. In 1710, it had been seen in the higher parts of the coast of the Lena, in the government of Irkutzk. In all these places it is now common, but is not yet found in the uncultivated regions of Kamtschatka.*

The great viper, or 'Fer de lance' (*Cras pedocephalus lanceolatus*), a native of the mainland of South America, and no less venomous than the rattlesnake, now ravages Martinique and St. Lucia, into which it was accidentally introduced by man, and exists in no other part of the West Indies.

Many parasitic insects which attack our persons, and some of which are supposed to be peculiar to our species, have been carried into all parts of the earth, and have as high a claim as man to a *universal* geographical distribution.

A great variety of insects have been transported in ships from one country to another, especially in warmer latitudes. The European house-fly has been introduced in this way into all the South Sea Islands. Notwithstanding the coldness of

* Gloger, Abänd. der Vögel, p. 103; Pallas, Zoog. Rosso-Asiat., tom. ii. p. 197.

our climate in England, we have been unable to prevent the cockroach (*Blatta orientalis*) from entering and diffusing itself in our ovens and kneading-troughs, and availing itself of the artificial warmth which we afford. It is well known also that beetles, and many other kinds of ligniperdous insects, have been introduced into Great Britain in timber; especially several North-American species. 'The commercial relations,' says Malte-Brun,* 'between France and India, have transported from the latter country the aphis, which destroys the apple-tree, and two sorts of Neuroptera, the *Lucifuga* and *Flavicola*, mostly confined to Provence and the neighbourhood of Bordeaux, where they devour the timber in the houses and naval arsenals.'

Among mollusks we may mention the *Teredo navalis*, which is a native of equatorial seas, but which, by adhering to the bottom of ships, was transported to Holland, where it has been most destructive to vessels and piles. The same species has also become naturalised in England, and other countries enjoying an extensive commerce. *Bulimus undatus*, a land species of considerable size, which is a native of Jamaica and other West Indian islands, has been imported, adhering to tropical timber, into Liverpool; and as Mr. Broderip informed me, is now naturalised in the woods near that town.

In all these and innumerable other instances we may regard the involuntary agency of man as strictly analogous to that of the inferior animals. Like them, we unconsciously contribute to extend or limit the geographical range and numbers of certain species, in obedience to general rules in the economy of nature, which are for the most part beyond our control.

* Syst. of Geog., vol. viii. p. 169.

CHAPTER XL.

ON THE GEOGRAPHICAL DISTRIBUTION AND MIGRATION OF SPECIES—*continued.*

GEOGRAPHICAL DISTRIBUTION AND MIGRATION OF FISH—OF TESTACEA—OF INSECTS—MOTHS SEEN FLYING 300 MILES FROM LAND—BOTANICAL GEOGRAPHY—DISPERSION OF PLANTS—AGENCY OF RIVERS AND CURRENTS—MARINE PLANTS—SARGASSUM OR GULF-WEED—AGENCY OF ANIMALS IN THE DISTRIBUTION OF PLANTS—AGENCY OF MAN, BOTH VOLUNTARY AND INVOLUNTARY, IN THE DISPERSION OF PLANTS.

Geographical distribution and migration of fish.—Although we are less acquainted with the habitations of marine animals than with those of terrestrial species, yet it is well ascertained that their distribution is governed by the same general laws.

On comparing the freshwater fish of Europe and North America, Sir John Richardson remarks, that the only species which is unequivocally common to the two continents is the pike (*Esox lucius*); and it is curious that this fish is unknown to the westward of the Rocky Mountains, the very coast which approaches nearest to the old continent.* According to the same author the genera of freshwater fish in China agree closely with those of the peninsula of India, but the species are not the same. 'As in the distribution,' he adds, 'of marine fish, the interposition of a continent stretching from the tropics far into the temperate or colder parts of the ocean, separates different ichthyological groups; so with respect to the freshwater species, the intrusion of arms of the sea running far to the northwards, or the interposition of a lofty mountain-chain, effects the same thing. The freshwater fish of the Cape of Good Hope and the South-American ones, are different from those of India and China.' †

Cuvier and Valenciennes, in their 'Histoire des Poissons,'

* Brit. Assoc. Reports, vol. v. p. 203.

† Report to the Brit. Assoc., 1845, p. 192.

observe that very few species of marine fish cross the Atlantic. But a great many species are common to the opposite sides of the Indian Ocean, inhabiting alike the Red Sea, the eastern coast of Africa, Madagascar, the Mauritius, the southern seas of China, the Malay Archipelago, the northern coasts of Australia, and the whole of Polynesia!* This very wide diffusion, says Sir J. Richardson, may have been promoted by chains of islands running east and west, which are wanting in the deep Atlantic. An archipelago extending far in longitude, favours the migration of fish by multiplying the places of deposit for spawn along the shores of islands, and on intervening coral banks; and in such places, also, fish find their appropriate food.

Although the marine shells on the opposite sides of the Isthmus of Panama are scarcely any one of them the same, yet nearly a third of the marine fishes, or 48 out of 158 species, have recently been ascertained by Dr. Günther to be common to the Pacific Ocean and Caribbean Sea. It has been said in explanation of the species of Testacea being distinct, that the coast on the east side of the isthmus is low, and the sea shallow, whereas the west or Pacific coast is abrupt, with perpendicular cliffs. The fish would be much more independent of the physical geography of the coast, and their eggs might be transported from one side of the isthmus to the other by birds.†

The flying fish are found (some stragglers excepted) only between the tropics: in receding from the line, they never approach a higher latitude than the fortieth parallel. The course of the Gulf-stream, however, and the warmth of its water, enable some tropical fish to extend their habitations far into the temperate zone; thus the chætodons, which abound in the seas of hot climates, are found among the Bermudas on the thirty-second parallel, where they are preserved in basins enclosed from the sea, as an important article of food for the garrison and inhabitants. Other fish, following the direction of the same great current, range from the coast of Brazil to the banks of Newfoundland.‡

* Richardson, Brit. Assoc. Reports, 1845, p. 190.

† Gardener's Chronicle, Feb. 23, 1867, p. 181.

‡ Sir J. Richardson, Brit. Assoc. Reports, 1845, p. 190.

All are aware that there are certain fish of passage which have their periodical migrations, like some tribes of birds. The salmon, towards the season of spawning, ascends the rivers for hundreds of miles, leaping up the cataracts which it meets in its course, and then retreats again into the depths of the ocean. The herring and the haddock, after frequenting certain shores, in vast shoals, for a series of years, desert them again, and resort to other stations, followed by the species which prey on them. Eels are said to descend into the sea for the purpose of producing their young, which are seen returning into the fresh water by myriads, extremely small in size, but possessing the power of surmounting every obstacle which occurs in the course of a river, by applying their slimy and glutinous bodies to the surface of the rocks, or the gates of a lock, even when dry, and so climbing over it.* Before the year 1800 there were no eels in Lake Wener, the largest inland lake in Sweden, which discharges its waters by the celebrated cataracts of Trolhättan. But according to Professor Nilsson, when a canal was opened uniting the river Gotha with the lake by a series of nine locks, eels were observed in abundance in the lake. It appears, therefore, that though they were unable to ascend the falls, they made their way by the locks, by which in a very short space a difference of level of 114 feet is overcome.

Gmelin says that the Anseres (wild geese, ducks, and others) subsist, in their migrations, on the spawn of fish; and that oftentimes, when they void the spawn, two or three days afterwards, the eggs retain their vitality unimpaired.† When there are many disconnected freshwater lakes in a mountainous region, at various elevations, each remote from the other, it has often been deemed inconceivable how they could all become stocked with fish from one common source; but it has been suggested, that the minute eggs of these animals may sometimes be entangled in the feathers of waterfowl. These, when they alight to wash and plume themselves in the water, may often unconsciously contribute to propagate swarms of fish, which, in due season, will supply them with food. Some of the water beetles, also, as the

* Phil. Trans. 1747, p. 395.

† Amœn. Acad., Essay 75.

Dyticidæ, are amphibious, and in the evening quit their lakes and pools; and, flying in the air, transport the minute ova of fishes to distant waters. In this manner some naturalists account for the fry of fish appearing occasionally in small pools caused by heavy rains.

GEOGRAPHICAL DISTRIBUTION AND MIGRATION OF TESTACEA.

The Testacea are a class of animals of peculiar importance to the geologist; because their remains are found in strata of all ages, and generally in a higher state of preservation than those of other organic beings.

Some forms are exclusively confined to warm, others to cold, latitudes. Marine currents flowing permanently in certain directions, and the influx at certain points of great bodies of fresh water, limit the extension of many species. Those which love deep water are arrested by shoals; others, fitted for shallow seas, cannot migrate across unfathomable abysses. The nature also of the ground has an important influence on the testaceous fauna, both on the land and beneath the waters. Certain species prefer a sandy, others a gravelly, and some a muddy sea-bottom. On the land, limestone is of all rocks the most favourable to the number and propagation of species of the genera Helix, Clausilia, Bulimus, and others. Professor E. Forbes showed in 1843,* as the result of his labours in dredging in the Ægean Sea, that there are eight well-marked regions of depth, each characterised by its peculiar testaceous fauna. The first of these, called the littoral zone, extends to a depth of two fathoms only; but this narrow belt is inhabited by more than 100 species. The second region, of which ten fathoms is the inferior limit, is almost equally populous; and a copious list of species is given as characteristic of each region down to the seventh, which lies between the depths of 80 and 105 fathoms. all the inhabited space below this being included in the eighth province, where no less than 65 species of shell-fish or mollusca have been taken. The majority of the shells in this lowest zone are white or transparent. Only two species are common to

* Brit. Assoc. Reports for 1843, p. 173.

all the eight regions, namely, *Arca lactea* and *Cerithium lima*.* These divisions of Edward Forbes were acknowledged by himself to be probably of no more than partial application, since they were deduced from observations made in an inland sea, and, therefore, under peculiar conditions. In that sea he believed that the zero of animal life would probably be reached at 1,800 feet, but we know that he was aware that this limit was not universal because he had cited a letter received by him in 1845 from his friend Goodsir, in which this naturalist gave an account of mollusca and other invertebrata dredged up in a living state from a depth of 1,800 feet near Davis Straits.†

Great range of some provinces and species.—In Europe conchologists distinguish between the arctic fauna, the southern boundary of which corresponds with the isothermal line of 32° F., and the Celtic, which, commencing with that limit as its northern frontier, extends southward to the mouth of the English Channel and Cape Finisterre, in France. From that point begins the Lusitanian fauna, which, according to the observations of Mr. M'Andrew in 1852, ranges to the Canary Islands. The Mediterranean province is distinct from all those above enumerated, although it has some species in common with each.

The Indo-Pacific region is by far the most extensive of all. It reaches from the Red Sea and the eastern coast of Africa, to the Indian Archipelago and adjoining parts of the Pacific Ocean. To the geologist it furnishes a fact of no small interest, by teaching us that one group of living species of mollusca may prevail throughout an area exceeding in magnitude the utmost limits we can as yet assign to any assemblage of contemporaneous fossil species. Mr. Cuming obtained more than 100 species of shells from the Eastern coast of Africa identical with those collected by himself at the Philippines and in the eastern coral islands of the Pacific Ocean, a distance of 12,000 miles, equal, says Darwin, to that from pole to pole.‡

* Report to the Brit. Assoc. 1843, p. 130.

† Forbes and Godwin-Austen, Natural History of European Seas, 1859, p. 51.

‡ Quart. Journ. Geol. Soc., 1846, vol. ii. p. 268.

Certain species of the genus *Ianthina* have a very wide range, being common to seas north and south of the equator. They are all provided with a beautifully contrived float, which renders them buoyant, facilitating their dispersion, and enabling them to become active agents in disseminating other species. Captain King took a specimen of *Ianthina fragilis* alive, a little north of the equator, so loaded with barnacles (*Pentelasmis*) and their ova that the upper part of its shell was invisible.

Helix putris (*Succinea putris*, Lam.) has a wide range in Europe, occurs also in Siberia, and is said to inhabit Newfoundland and parts of North America. It was found by Captain Hutton in Afghanistan.* As this animal inhabits constantly the borders of pools and streams where there is much moisture, it is not impossible that different waterfowl have been the agents of spreading some of its minute eggs, which may have been entangled in their feathers. The freshwater snail, *Lymnea palustris*, so abundant in English ponds, ranges uninterruptedly from Europe to Cashmere, and thence to the eastern part of Asia. *Helix aspersa*, one of the commonest of our larger land-shells, is found in St. Helena and other distant countries. Some conchologists have conjectured that it was accidentally imported into St. Helena in some ship; for it is an eatable species.

As an illustration of the power of such mollusca to retain life during a long voyage without air or nourishment, I may mention that four individuals of a large species of landshell (*Bulimus*), from Valparaiso, were brought to England by Lieutenant Graves, who accompanied Captain King in his expedition to the Straits of Magellan. They had been packed up in a box, and enveloped in cotton: two for a space of thirteen, one for seventeen, and a fourth for upwards of twenty months: but when they were exposed by Mr. Broderip to the warmth of a fire in London, and provided with tepid water, I saw them revive and feed greedily on lettuce leaves.

Perhaps no species has a better claim to be called cosmopolite than one of our British bivalves, *Saxicava rugosa*. It

* J. Gwyn Jeffreys, British Conchology, p. 152.

is spread over all the north-polar seas, and ranges in one direction through Europe to Senegal, occurring on both sides of the Atlantic; while in another it finds its way into the North Pacific, and thence to the Indian Ocean. Nor do its migrations cease till it reaches the Australian seas.

A British brachiopod, named *Terebratula caput serpentis*, is common, according to Professor E. Forbes, to both sides of the North Atlantic, and to the South-African and Chinese seas. The wide range in space of this species is a fact of peculiar interest to the geologist, because its range in time also is exceptionally great, being one of the very few species which have been traced in a fossil state as far back as the Cretaceous Period.

Mode of diffusion of Testacea.—Notwithstanding the proverbially slow motion of snails and mollusks in general, and although many aquatic species adhere constantly to the same rock for their whole lives, they are by no means destitute of provision for disseminating themselves rapidly over a wide area. 'Some Mollusca,' says Professor E. Forbes, 'migrate in their larva state, for all of them undergo a metamorphosis either in the egg or out of the egg. The Gasteropoda commence life under the form of a small spiral shell, and an animal furnished with ciliated wings, or lobes, like a pteropod, by means of which it can swim freely, and in this form can migrate with ease through the sea.'*

We are accustomed to associate in our minds the idea of the great locomotive powers with the most mature and perfect state of each species of invertebrate animal, especially when they undergo a series of transformations; but in all the Mollusca the reverse is true. The fry of the cockle, for example (*Cardium*), possess, when young or in the larva state, an apparatus which enables them both to swim and to be carried along easily by a marine current. (See fig. 141.)

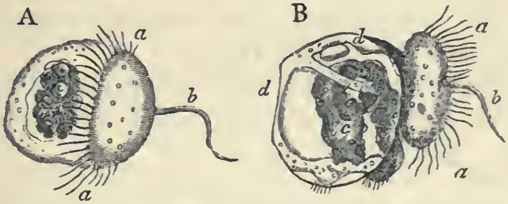
These small bodies here represented, which bear a considerable resemblance to the fry of univalve, or gasteropodous shells, above mentioned, are so minute at first as to be only just visible to the naked eye. They begin to move about from the moment they are hatched by means of the long

* Edin. New Phil. Journ. April, 1844.

cilia, *a*, *a*, placed on the edges of the locomotive disk or velum. This disk shrinks up as they increase in size, and gradually disappears, no trace of it being visible in the perfect animal.

Some species of shell-bearing Mollusca lay their eggs in a sponge-like nidus, wherein the young remain enveloped for a

Fig. 141.



The young fry of a cockle (Cardium pygmæum), from Loven's Kongl. Vetenskaps Akadem. Handling, 1848.

A. The young just hatched, magnified 100 diameters.
B. The same farther advanced.
a. The ciliated organ of locomotion with its filamentous appendage *b*.
c. The rudimentary intestine.
d. The rudimentary shell.

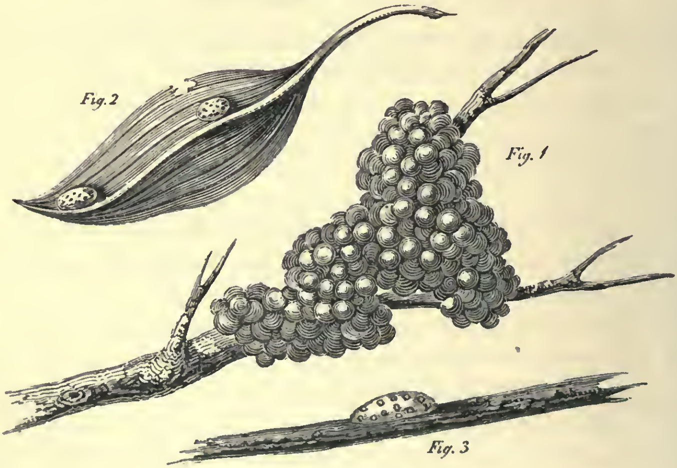
time after their birth; and this buoyant substance floats far and wide as readily as sea-weed. The young of other viviparous tribes are often borne along entangled in sea-weed. Sometimes they are so light, that, like grains of sand, they can be easily moved by currents. Balani and Serpulæ are sometimes found adhering to floating cocoa-nuts, and even to fragments of pumice far out at sea. It is probable, indeed, that the porous and sponge-like texture of pumice causes it to be a vehicle for the transport of eggs of mollusks and insects and of the seeds of plants far more effective in many regions than has been hitherto suspected. Mr. Bates saw pieces of it floating on the river Amazons 1,200 miles from the nearest volcanos of the Andes, from which it must have been derived. He also observed other fragments 900 miles lower down the river, which in the rainy season are floated at the rate of from three to five miles an hour.* They must often reach the sea, and may then be carried by currents hundreds of miles farther.

* Naturalist of the Amazons, vol. ii. p. 170.

In rivers and lakes, on the other hand, aquatic univalves usually attach their eggs to leaves and sticks which have fallen into the water, and which are liable to be swept away, during floods, from tributaries to the main streams, and from thence to all parts of the same basin. Particular species may thus migrate during one season from the head waters of the Mississippi, or any other great river, to countries bordering the sea, at the distance of many thousand miles. An illustration of the mode of attachment of these eggs will be seen in the annexed cut (fig. 142).

A lobster (*Astacus marinus*) was taken alive covered with living mussels (*Mytilus edulis*);* and a large female crab

Fig. 142.



Eggs of freshwater Mollusks.

Fig. 1. Eggs of *Ampullaria ovata* (a fluviatile species) fixed to a small sprig which had fallen into the water.

Fig. 2. Eggs of *Planorbis albus*, attached to a dead leaf lying under water.

Fig. 3. Eggs of the common Limneus (*L. vulgaris*), adhering to a dead stick under water.

(*Cancer pagurus*), covered with oysters, and bearing also *Anomia ephippium*, and Actiniæ, was also taken in 1832, off the English coast. The oysters, seven in number, included individuals of six years' growth, and the two largest were four inches long and three inches and a half broad.†

* The specimen was preserved in the Museum of the Zool. Soc. of London.

† Mr. Broderip observed that this crab, which was apparently in perfect health, could not have cast her shell for six years, whereas some naturalists have stated that the species moults annually, without limiting the moulting period to the early stages of the growth of the animal.

From this example we learn the manner in which oysters may be diffused over every part of the sea where the crab wanders; and if they are at length carried to a spot where there is nothing but fine mud, the foundation of a new oyster-bank may be laid on the death of the crab. In this instance the oysters survived the crab many days, and were killed at last only by long exposure to the air.

GEOGRAPHICAL DISTRIBUTION AND MIGRATION OF INSECTS.

The entomological provinces coincide very closely with those of the higher animals as already described. Few species have a very wide range, but there are exceptions to this rule, and among them may be mentioned our painted lady butterfly (*Vanessa cardui*), which re-appears at the Cape of Good Hope and in New Holland and Japan with scarcely a varying streak.* The same species is said to be one of the few insects which are universally dispersed over the earth, being found in Europe, Asia, Africa, America, and Australia, although it rarely occurs within the tropics except in a few mountain regions. Its wide range seems to imply a capacity enjoyed by few species, of enduring a great diversity of temperature, and is the more interesting because of the migratory instinct which it sometimes displays.

A vast swarm of this species, forming a column from ten to fifteen feet broad, was in 1826 observed in Switzerland, in the Canton de Vaud: they traversed the country with great rapidity from north to south, all flying onwards in regular order, close together, and not turning from their course on the approach of other objects. Professor Bonelli, of Turin, observed, in March of the same year, a similar swarm of the same species, also directing their flight from north to south, in Piedmont, in such immense numbers, that at night the flowers were literally covered with them. They had been traced from Coni, Raconi, Susa, &c. A similar flight at the end of the last century is recorded by M. Louch, in the Memoirs of the Academy of Turin.

The European hive-bee (*Apis mellifica*), although not a

* Kirby and Spence, vol. iv. p. 487; and other authors.

native of the New World, is now established both in North and South America. It was introduced into the United States by some of the early settlers, and has since overspread the vast forests of the interior, building hives in the decayed trunks of trees. 'The Indians,' says Irving, 'consider them as the harbinger of the white man, as the buffalo is of the red man, and say that in proportion as the bee advances the Indian and the buffalo retire. It is said,' continues the same writer, 'that the wild bee is seldom to be met with at any great distance from the frontier, and that they have always been the heralds of civilisation, preceding it as it advanced from the Atlantic borders. Some of the ancient settlers of the west even pretend to give the very year when the honey bee first crossed the Mississippi.'* The same species is now also naturalised in Van Diemen's Land and New Zealand.

As almost all insects are winged, they can readily spread themselves wherever their progress is not opposed by uncongenial climates, or by seas, mountains, and other physical impediments; and these barriers they can sometimes surmount by abandoning themselves to violent winds, which, as I shall afterwards state, when speaking of the dispersion of seeds (p. 390), may in a few hours carry them to very considerable distances. On the Andes some sphinxes and flies have been observed by Humboldt, at the height of 19,180 feet above the sea, and which appeared to him to have been involuntarily carried into these regions by ascending currents of air.†

Inundations of rivers, observes Kirby, if they happen at any season except in the depth of winter, always carry down a number of insects, floating on the surface of bits of stick, weeds, &c.; so that when the waters subside, the entomologist may generally reap a plentiful harvest. In the dissemination, moreover, of these minute beings, as in that of plants, the larger animals play their part. Insects are, in numberless instances, borne along in the coats of animals, or the feathers of birds; and the eggs of some species are capable,

* Washington Irving's Tour in the Prairies, ch. ix.

† Description of the Equatorial Regions.—Malte-Brun, vol. v. p. 379.

like seeds, of resisting the digestive powers of the stomach, and after they are swallowed with herbage, may be ejected again unharmed in the dung.

White mentions a remarkable shower of aphides which seem to have emigrated, with an east wind, from the great hop plantations of Kent and Sussex, and blackened the shrubs and vegetables where they alighted at Selborne, spreading at the same time in great clouds all along the vale from Farnham to Alton. These aphides are sometimes accompanied by vast numbers of the common lady-bird (*Coccinella septempunctata*), which feeds upon them.*

It is remarkable, says Kirby, that many of the insects which are occasionally observed to emigrate, as, for instance, the Libellulæ, Coccinellæ, Carabi, Cicadæ, &c., are not usually social insects; but seem to congregate, like swallows, merely for the purpose of emigration.† Here, therefore, we have an example of an instinct developing itself on certain rare emergencies, causing unsocial species to become gregarious and to venture sometimes even to cross the ocean.

The armies of locusts (*Gryllus migratorius*), which darken the air in Africa and traverse the globe from Turkey to our southern counties in England, are well known to all, and their vast geographical range will again be alluded to (Chap. XLII.) When the western gales sweep over the Pampas they bear along with them myriads of insects of various kinds. As a proof of the manner in which species may be thus diffused, I may mention that when the Creole frigate was lying in the outer roads off Buenos Ayres, in 1819, at the distance of six miles from the land, her decks and rigging were suddenly covered with thousands of flies and grains of sand. The sides of the vessel had just received a fresh coat of paint, to which the insects adhered in such numbers as to spot and disfigure the vessel, and to render it necessary partially to renew the paint.‡ The late Admiral W. H. Smyth was obliged to repaint his vessel, the Adventure, in the Mediter-

* Kirby and Spence, vol. ii. p. 9. 1817.

† Ibid.

‡ I am indebted to Lieutenant Graves, R.N., for this information.

ranean, from the same cause. He was on his way from Malta, to Tripoli, when a southern wind blowing from the coast of Africa, then one hundred miles distant, drove such myriads of flies upon the fresh paint, that not the smallest point was left unoccupied by insects.

Moths seen flying 300 *miles from land.*—Captain Henry Toynbee has put on record some striking examples of the great distance from land at which the larger Lepidoptera are occasionally seen on the wing. A female of the large *Sphynx convolvuli* flew on board his ship, the Hotspur, East Indiaman, in lat. 12° 09′ N. and long. 21° 17′ W., a point 300 miles from the nearest coast of Africa, and about 210 miles from the Cape de Verde Islands, from which last it is supposed to have come, as the prevailing winds at the time were north-westerly. Two individuals of the common Death's Head Moth (*Acherontia atropos*) also flew on board the Hotspur during the same homeward voyage, in lat. 40° 29′ N.—long. 15° W., or 260 miles from the nearest land (the coast of Portugal) after an easterly gale. They had already traversed more than two-thirds of the distance from Europe to Madeira, and the case affords a good illustration of the manner in which islands far out at sea may be peopled with insects from the nearest continents.*

To the southward of the river Plate, off Cape St. Antonio, and at the distance of fifty miles from land, several large dragon-flies alighted on the Adventure frigate, during Captain King's expedition to the Straits of Magellan. If the wind abates when insects are thus crossing the sea, the most delicate species are not necessarily drowned; for many can repose on the water without sinking. The slender long-legged Tipulæ, when driven out far from our coast, have been seen standing on the surface of the sea, and they took wing immediately on being approached.† Exotic beetles are sometimes thrown on our shore, which revive after having been long drenched in salt water; and the periodical appearance of some conspicuous butterflies

* Both the above-mentioned insects were shown at a meeting of the Zoological Society by Mr. Flower, May 22, 1866.

† I state this fact on the authority of my friend, the late Mr. John Curtis, the able entomologist.

amongst us, after being unseen some for five, others for fifty years, has been ascribed, not without probability, to the agency of the winds.

BOTANICAL GEOGRAPHY.

Scarcely 1,400 species of plants appear to have been known and described by the Greeks, Romans, and Arabians. At present, more than 3,000 species are enumerated as natives of our own island.* In other parts of the world there have been now collected more than 100,000 reputed species, specimens of which are preserved in European herbariums. It was not to be supposed, therefore, that the ancients should have acquired any correct notions respecting what has been called the geography of plants, although the influence of climate on the character of the vegetation could hardly have escaped their observation.

Antecedently to investigation, there was no reason for presuming that the vegetable productions, growing wild in the eastern hemisphere, should be unlike those of the western, in the same latitude; nor that the plants of the Cape of Good Hope should be unlike those of the south of Europe; situations where the climate is little dissimilar. The contrary supposition would have seemed more probable, and we might have anticipated an almost perfect identity in the plants which inhabit corresponding parallels of latitude at equal heights above the sea. The discovery, therefore, that each separate region of the globe, both of the land and water, is occupied, in the vegetable as well as in the animal world, by distinct groups of species, and that most of the exceptions to this general rule are referable to disseminating causes now in operation, is eminently calculated to prepare us to receive with favour any hypothesis respecting the first introduction of species which is most consistent with such phenomena.

Botanical regions.—Humboldt was among the first to promulgate philosophical views on the distinctness of the vegetable productions of different regions of the globe.

* Barton's Lectures on the Geography of Plants, p. 2. 1827.

Every hemisphere, he said, is inhabited by different species of plants, and it is not by the diversity of climates that we can attempt to explain why equinoctial Africa has no Laurineæ, and the New World no Heaths;* or why the Calceolariæ are found only in the southern hemisphere.

'We can conceive,' he adds, 'that a small number of the families of plants, for instance, the Musaceæ and the Palms, cannot belong to very cold regions, on account of their internal structure and the importance of certain organs; but we cannot explain why no one of the Melastomas (a family allied to the Myrtles) vegetates north of the parallel of thirty degrees; or why no rose-tree belongs to the southern hemisphere. Analogy of climates is often found in the two continents without identity of productions.'†

The luminous essay of Auguste de Candolle on 'Botanical Geography' (1820) presents us with the fruits of his own researches and those of Humboldt, Brown, and other eminent botanists, so arranged, that the principal phenomena of the distribution of plants are exhibited in connection with the causes to which they are supposed to be referable.‡ 'It might not, perhaps, be difficult,' observes this writer, 'to find two points, in the United States and in Europe, or in equinoctial America and Africa, which present all the same circumstances: as, for example, the same temperature, the same height above the sea, a similar soil, an equal dose of humidity; yet nearly all, *perhaps all*, the plants in these two similar localities shall be distinct. A certain degree of analogy, indeed, of aspect, and even of structure, might very possibly be discoverable between the plants of the two localities in question; but the *species* would in general be different. Circumstances, therefore, different from those which now determine the *stations*, have had an influence on the *habitations* ofplants.'

It may be as well to define in this place the technical sense in which the words printed in italics are here used: *station*

* The common heath (*Erica vulgaris*, L.) has, since Humboldt wrote, been found growing wild in one spot in Massachusetts, north of Boston; but this case is quite exceptional.

† Pers. Nar., vol. v. p. 180.

‡ Essai Elémentaire de Géographie Botanique. Extrait du 18me vol. du Dict. des Sci. Nat. 1820.

indicates the peculiar nature of the locality where each species is accustomed to grow, and has reference to climate, soil, humidity, light, elevation above the sea, and other analogous circumstances; whereas, by *habitation* is meant a general indication of the country where a plant grows wild. Thus the *station* of a plant may be a salt-marsh, a hill-side, the bed of the sea, or a stagnant pool. Its *habitation* may be Europe, North America, or New Holland, between the tropics. The study of *stations* has been styled the topography, that of *habitations* the geography, of botany. The terms thus defined, express each a distinct class of ideas, which have been often confounded together, and which are equally applicable in zoology.

In farther illustration of the principle above alluded to, that difference of longitude, independently of any influence of temperature, is accompanied by a great, and sometimes a complete, diversity in the species of plants, De Candolle observed, that, out of 2,891 species of phænogamous plants described by Pursh as known in 1820 in the United States, there were only 385 common to northern or temperate Europe.

On comparing New Holland with Europe, Mr. Brown ascertained that, out of 4,100 species, then discovered in Australia, there were only 166 common to Europe, and of this small number there were some few which may have been transported thither by man. Almost all of the 166 species were cryptogamic, and the rest consist, in nearly every case, of phænogamous plants which also inhabit intervening regions.

But it is still more remarkable that there should be an almost equal diversity of species, in distant parts of the ancient continent between which there is an uninterrupted land communication. Thus there is one assemblage of species in China, another in the countries bordering the Black Sea and the Caspian, a third in those surrounding the Mediterranean, a fourth on the great platforms of Siberia and Tartary, and so forth.

The distinctness of the groups of indigenous plants, in the same parallel of latitude, is greatest, as in the case of animals before mentioned, where continents are disjoined

by a wide expanse of ocean. In the northern hemisphere, near the pole, where the extremities of Europe, Asia, and America unite or approach near to one another, a considerable number of the same species of plants are found, common to the three continents. But it has been remarked, that these plants, which are thus so widely diffused in the arctic regions, are also found in the chain of the Aleutian Islands, which stretch almost across from America to Asia, and which may probably have served as the channel of communication for the partial blending of the floras of the adjoining regions. De Candolle enumerated twenty great botanical provinces, inhabited by indigenous and aboriginal plants; and his son Alphonse, a distinguished living botanist, has made a further subdivision into twenty-seven provinces, between which the lines of demarcation are by no means ill-defined.*

There are, however, not a few species which are common to two or more than two of these provinces, and often representative forms which some naturalists would class as mere geographical varieties. The six ornithological divisions of the globe before alluded to (p. 337), four of them in the Old World and two in the New, are not on the whole inapplicable to plants, if we wish to take a more large and comprehensive view of the leading features in their geographical distribution, especially as regards genera and families.

This holds true, particularly of the Neoarctic and Neotropical regions, each of which contains a distinct assemblage of peculiar vegetable forms. Those of the table-land of Brazil, which has an elevation of from 2,000 to 4,000 feet, are described by Sir Charles Bunbury, after he had explored the district, as belonging for the most part to generic types, little known except to botanists, for they have not been cultivated in Europe. But when he descended from the Brazilian uplands towards the south, or to the grassy plains of Uruguay and La Plata, he found plants still belonging to the predominant South-American types, though represented by different and local species. Such affinity between the specific forms proper to the more elevated and to the lower stations agrees well with the idea of certain original types

* Alph. de Candolle, Monogr. des Campanulées. Paris, 1830.

having been gradually adapted by variation and natural selection to all the diversified conditions of the surface of the land.

The Pampas and banks of the Plata are also remarkable for the extraordinary manner in which some foreign European plants, especially the thistles and trefoils, have overpowered the indigenous vegetation.* The intruders have been introduced by man sometimes unintentionally, and, having naturalised themselves, have become more conspicuous than any of the native products of the soil. They illustrate a principle before laid down, that the organic beings of each great region which man finds in possession of wide areas are not those which are most fitted of all contemporary species to flourish there to the exclusion of all others. They appear to be simply the modified descendants of such an older fauna and flora as happened to pre-exist under a somewhat different phase of the earth's physical geography, or they are the offspring of colonists which by natural means were able to reach those lands. But the same organisms are powerless to maintain their ground in the struggle for life if brought into competition with species from distant regions which would never without the aid of man have come into contact with them.

Marine plants.—The vegetation of the sea, like that of the land, is divisible into different provinces each inhabited by distinct species, but these provinces are fewer in number because the temperature of the ocean is more uniform than that of the atmosphere, and because the area of land bears a small proportion to that of water, so that the migration of marine plants is not so often stopped by barriers of land as is that of the terrestrial species by an intervening ocean. It is a remarkable fact that Dr. Hooker has been able to identify no less than a fifth part of the antarctic algæ, excluding the New Zealand and Tasmanian groups, with British species. Yet there is a much smaller proportion of cosmopolite species among the algæ than among the terrestrial cellular cryptogams, such as lichens, mosses, and Hepaticæ.

* Sir C. Bunbury, 'Characters of S. American Vegetation,' Fraser's Magazine. July, 1867.

Dispersion of plants.—The fact last alluded to, of the ubiquitous character of cryptogamous plants, deserves special attention. Linnæus observed that, as the germs of plants of this class, such as mosses, fungi, and lichens, consist of an impalpable powder, the particles of which are scarcely visible to the naked eye, there is no difficulty in accounting for their being dispersed throughout the atmosphere, and carried to every point of the globe where there is a station fitted for them. Lichens in particular ascend to great elevations, sometimes growing on bare rocks two thousand feet above the line of perpetual snow, where the mean temperature is nearly at the freezing point. This elevated position must contribute greatly to facilitate the dispersion of those buoyant particles of which their fructification consists.*

Some have inferred, from the springing up of mushrooms whenever particular soils and decomposed organic matter are mixed together, that the production of fungi is accidental, and not analogous to that of perfect plants. But Fries, whose authority on these questions is entitled to the highest respect, has shown the fallacy of this argument in favour of the old doctrine of equivocal generation. 'The sporules of fungi,' says this naturalist, 'are so infinite, that in a single individual of *Reticularia maxima*, I have counted above ten millions, and so subtile as to be scarcely visible, often resembling thin smoke; so light that they may be raised perhaps by evaporation into the atmosphere, and dispersed in so many ways by the attraction of the sun, by insects, wind, elasticity, adhesion, &c., that it is difficult to conceive a place from which they may be excluded.'†

The club-moss called *Lycopodium cernuum* affords a striking example of a cryptogamous plant universally distributed over all equinoctial countries. It scarcely ever passes beyond the northern tropic, except in one instance, where it appears around the hot-springs in the Azores, although it is neither an inhabitant of the Canaries nor of Madeira. Doubtless its microscopic sporules are everywhere present, ready to germinate on any spot where they can enjoy throughout

* Linn., Tour in Lapland, vol. ii. p. 282.

† Fries, cited by Lindley, Introd. to Nat. Syst. of Botany.

the year the proper quantity of warmth, moisture, light, and other conditions essential to the species.

No less than 200 species of lichen were brought home from the southern hemisphere by the Antarctic Expedition under Sir James Ross, and almost every one of these was ascertained to be also an inhabitant of the northern hemisphere, and most of them European.

When we contrast the cosmopolite character of this class of plants with the comparatively limited range of most of the phænogamous species, we cannot fail to perceive how intimately the geographical distribution of each is related to its powers of dispersion. But, in order to see a connection between these phenomena, we must first assume that each species has one birthplace, and that it has radiated in all directions in which it is possible for it to spread from the original point or centre where it was first formed.

The most active of the inanimate agents provided by nature for scattering the seeds of plants over the globe, are the movements of the atmosphere and of the ocean, and the constant flow of water from the mountains to the sea. To begin with the winds: a great number of seeds are furnished with downy and feathery appendages, enabling them, when ripe, to float in the air, and to be wafted easily to great distances by the most gentle breeze. Other plants are fitted for dispersion by means of an attached wing, as in the case of the fir-tree, so that they are caught up by the wind as they fall from the cone, and are carried to a distance. Amongst the comparatively small number of plants known to Linnæus, no less than 138 genera are enumerated as having winged seeds.

As winds often prevail for days, weeks, or even months together, in the same direction, these means of transportation may sometimes be without limits; and even the heavier grains may be borne through considerable spaces, in a very short time, during ordinary tempests; for strong gales, which can sweep along grains of sand, often move at the rate of about forty miles an hour, and if the storm be very violent, at the rate of fifty-six miles.* The hurricanes of tropical regions,

* Annuaire du Bureau des Longitudes.

which root up trees and throw down buildings, sweep along at the rate of ninety miles an hour; so that, for however short a time they prevail, they may carry even the heavier fruits and seeds over friths and seas of considerable width, and doubtless are often the means of introducing into islands the vegetation of adjoining continents. Whirlwinds are also instrumental in bearing along heavy vegetable substances to considerable distances. Slight ones may frequently be observed in our fields, in summer, carrying up haycocks into the air, and then letting fall small tufts of hay far and wide over the country; but they are sometimes so powerful as to dry up lakes and ponds, and to break off the boughs of trees, and carry them up in a whirling column of air.

Dr. Franklin tells us, in one of his letters, that he saw, in Maryland, a whirlwind which began by taking up the dust which lay in the road, in the form of a sugar-loaf with the pointed end downwards, and soon after grew to the height of forty or fifty feet, being twenty or thirty in diameter. It advanced in a direction contrary to the wind; and although the rotatory motion of the column was surprisingly rapid, its onward progress was sufficiently slow to allow a man to keep pace with it on foot. Franklin followed it on horseback, accompanied by his son, for three quarters of a mile, and saw it enter a wood, where it twisted and turned round large trees with surprising force. These were carried up in a spiral line, and were seen flying in the air, together with boughs and innumerable leaves, which, from their height, appeared reduced to the size of flies. As this cause operates at different intervals of time throughout a great portion of the earth's surface, it may be the means of bearing not only plants but insects, land testacea and their eggs, with many other species of animals, to points which they could never otherwise have reached, and from which they may then begin to propagate themselves again as from a new centre.

Agency of rivers and currents.—In considering, in the next place, the instrumentality of the aqueous agents of dispersion, I cannot do better than cite the words of one of our ablest botanical writers. 'The mountain stream or

torrent,' observes Keith, 'washes down to the valley the seeds which may accidentally fall into it, or which it may happen to sweep from its banks when it suddenly overflows them. The broad and majestic river, winding along the extensive plain, and traversing the continents of the world, conveys to the distance of many hundreds of miles the seeds that may have vegetated at its source. Thus the southern shores of the Baltic are visited by seeds which grew in the interior of Germany, and the western shores of the Atlantic by seeds that have been generated in the interior of America.'* Fruits, moreover, indigenous to America and the West Indies, such as that of the *Mimosa scandens*, the cashew-nut, and others, have been known to be drifted across the Atlantic by the Gulf-stream, on the western coasts of Europe, in such a state that they might have vegetated had the climate and soil been favourable. Among these the *Guilandina Bonduc*, a leguminous plant, is particularly mentioned, as having been raised from a seed found on the west coast of Ireland.†

Sir Hans Sloane states, that several kinds of beans cast ashore on the Orkney Isles, and Ireland, but none of which appear to have naturalised themselves, are derived from trees which grow in the West Indies, and many of them in Jamaica. He conjectures that they might have been conveyed by rivers into the sea, and then by the Gulf-stream, to greater distances.

The absence of liquid matter in the composition of seeds renders them comparatively insensible to heat and cold, so that they may be carried without detriment through climates where the plants themselves would instantly perish. Such is their power of resisting the effects of heat, that Spallanzani mentions some seeds that germinated after having been boiled in water.‡ Sir John Herschel informed me that he has sown at the Cape of Good Hope the seeds of the *Acacia lophanta* after they had remained for twelve hours in water of 140° Fahrenheit, and they germinated far more rapidly than unboiled seeds. He also stated that an emi-

* System of Physiological Botany, vol. ii. p. 405.

† Brown, Append. to Tuckey, No. v. p. 481.

‡ System of Physiological Botany, vol. ii. p. 403.

nent botanist, Baron Ludwig, could not get the seeds of a species of cedar to grow at the Cape till they were thoroughly boiled.

When, therefore, a strong gale, after blowing violently off the land for a time, dies away, and the seeds alight upon the surface of the waters, or wherever the ocean, by eating away the sea-cliffs, throws down into its waves plants which would never otherwise reach the shores, the tides and currents become active instruments in assisting the dissemination of various classes of the vegetable kingdom. The pandanus and many other plants have been distributed in this way over the islands of the Pacific.

In a collection of 600 plants from the neighbourhood of the river Zaire, in Africa, the late Dr. Robert Brown found that thirteen species were also met with on the opposite shores of Guiana and Brazil. He remarked that most of these plants were found only on the lower parts of the river Zaire, and were chiefly such as produced seeds capable of retaining their vitality a long time in the currents of the ocean. Dr. J. Hooker informs me that after an examination of a great many insular floras, he has found that no one of the large natural orders is so rich in species common to other countries as the Leguminosæ. The seeds in this order, which comprises the largest proportion of widely diffused littoral species, are better adapted than those of any other plants for water-carriage.

Mr. Darwin has made a series of experiments to ascertain the number of days for which the seeds and fruits of various plants could be immersed in salt water without injury, and he found that out of 87 kinds, 64 germinated after they had been 28 days in salt water, and some survived an immersion of 37 days. According to the average rate at which oceanic currents run, he came to the conclusion that a large number of seeds might be carried uninjured for nearly 1,000 miles across the sea.*

Currents and winds in the arctic regions drift along icebergs covered with an alluvial soil, on which pine-saplings and a variety of herbaceous plants are seen growing, all of

* Origin of Species, chap. xi.

which may continue to vegetate on some distant shore where the ice-island may be stranded.

Dispersion of marine plants.—With respect to marine vegetation, the seeds, being in their native element, may remain immersed in water without injury for indefinite periods, so that there is no difficulty in conceiving the diffusion of species wherever uncongenial climates, contrary currents, and other causes do not interfere. All are familiar with the sight of the floating sea-weed :

> Flung from the rock on ocean's foam to sail,
> Where'er the surge may sweep, the tempest's breath prevail.

I have before called attention (p. 389) to the interesting fact that one-fifth of all the algæ found in the antarctic regions in 1841-3, by Dr. J. Hooker, were of species common to the British seas. He has suggested that cold currents which prevail from Cape Horn to the equator, and are there met by other cold waters, may by their direct influence, as well as by their temperature, facilitate the passage of antarctic species to the Arctic Ocean.

Remarkable accumulations of that species of sea-weed generally known as gulf-weed, or sargassum, occur north of the equator in the Northern Atlantic. Columbus and other navigators, who first encountered these banks of algæ, compared them to vast inundated meadows, and stated that they retarded the progress of their vessels. This mass of floating vegetation, exceeding the British Isles in area, lies between latitudes 20° and 35° to the south-west of Europe.

Sir Hans Sloane stated in 1696 that this weed grows on the rocks about Jamaica, and is known to be 'carried by the winds and currents towards the coast of Florida and thence into the North-American ocean, where it lies very thick on the surface of the sea.'*

Humboldt first suggested that it occupies an eddy in that part of the Atlantic where the Gulf-stream is met by the current from the north ; and Maury gives a similar explanation of another large bank of kelp and drift-weed in the North Pacific, to the northward of the Sandwich Islands,

* Phil. Trans. 1696.

and of another in the Southern Ocean around Kerguelen's Land, between lat. 40° and 54°.*

The late Robert Brown inclined to the opinion that the original source of the gulf-weed might be some parts of the coasts of the Gulf of Florida. When floating on the ocean it propagates itself rapidly by new fronds which are continually pushed out from the old ones; and the larger portion of it being produced under such peculiar circumstances, the plant may perhaps become so modified as not to be easily identifiable with the original stock from which it is derived.† Edward Forbes conceived that this weed first grew on an old coast-line since submerged; this coast having formed the western extremity of the continent of Europe and Northern Africa, which then extended far into the Atlantic.‡ But the great depth of the ocean, ranging from 1,000 to 10,000 feet, and often to a still greater depth, which prevails over a great part of the area assumed by this hypothesis to have been turned from land into sea since the Miocene epoch, makes me consider it far more probable, that, instead of growing on a bank which has sunk down, the gulf-weed has been drifted from some part of America.

As proof of the extent to which sea-weed is drifted, I may mention that along the northern edge of the Gulf-stream Dr. Hooker found *Fucus nodosus* and *F. serratus*, which he traced all the way from lat. 36° N. to England. The hollow pod-like receptacles in which the spores of many algæ are lodged, and the filaments attached to the seed-vessels of others, seem intended to give buoyancy. It may also be remarked that these hydrophytes are in general *proliferous*, so that the smallest fragment of a branch can be developed into a perfect plant. The spores, moreover, of the greater number of species are enveloped with a mucous matter like that which surrounds the eggs of some fish, and which not only protects them from injury, but serves to attach them to floating bodies or to rocks.

* See map of Sargassum seas, taken from Maury by Andrew Murray, Geog. Dist. of Mammals, 1866.

† R. Brown, Mode of Propagation of Gulf-weed, Miscell. Works, vol. i. Ray Society, 1866.

‡ E. Forbes, Fauna and Flora, &c., 1846, vol. i. p. 349.

Agency of animals in the distribution of plants.—But we have as yet considered part only of the fertile resources of nature for conveying seeds to a distance from their place of growth. The various tribes of animals are busily engaged in furthering an object whence they derive such important advantages. Sometimes an express provision is found in the structure of seeds to enable them to adhere firmly by prickles, hooks, and hairs to the coats of animals, or feathers of the winged tribe, to which they remain attached for weeks, or even months, and are borne along into every region whither birds or quadrupeds may migrate. Linnæus enumerates fifty genera of plants, and the number now known to botanists is much greater, which are armed with hooks, by which, when ripe, they adhere to the coats of animals. Most of these vegetables, he remarks, require a soil enriched with dung. Few have failed to mark the locks of wool hanging on the thorn-bushes, wherever the sheep pass, and it is probable that the wolf and other beasts of prey never give chase to herbivorous animals without being unconsciously subservient to this part of the vegetable economy.

A deer has strayed from the herd when browsing on some rich pasture, when he is suddenly alarmed by the approach of his foe. He instantly takes to flight, dashing through many a thicket, and swimming across many a river and lake. The seeds of the herbs and shrubs which have adhered to his smoking flanks, and even many a thorny spray, which has been torn off, and has fixed itself in his hairy coat, are brushed off again in other thickets and copses. Even on the spot where the victim is devoured many of the seeds which he had swallowed immediately before the chase may be left on the ground uninjured, and ready to spring up in a new soil.

The passage, indeed, of undigested seeds through the stomachs of animals is one of the most efficient causes of the dissemination of plants, and is, of all others, perhaps the most likely to be overlooked. Few are ignorant that a portion of the oats eaten by a horse preserve their germinating faculty in the dung. The fact of their being still nutritious is not lost on the sagacious rook. To many, says Linnæus, it seems

extraordinary, and something of a prodigy, that when a field is well tilled and sown with the best wheat, it frequently produces darnel or the wild oat, especially if it be manured with new dung; they do not consider that the fertility of the smaller seeds is not destroyed in the stomachs of animals.*

Some birds of the order Passeres devour the seeds of plants in great quantities, which they eject again in very distant places, without destroying their faculty of vegetation: thus a flight of larks will fill the cleanest field with a great quantity of various kinds of plants, as the melilot trefoil (*Medicago lupulina*), and others whose seeds are so heavy that the wind is not able to scatter them to any distance.† In like manner the blackbird and misselthrush, when they devour berries in too great quantities, are known to consign them to the earth undigested in their excrement.‡

Pulpy fruits serve quadrupeds and birds as food, while their seeds, often hard and indigestible, pass uninjured through the intestines, and are deposited far from their original place of growth in a condition peculiarly fit for vegetation.§ So well are the farmers, in some parts of England, aware of this fact, that when they desire to raise a quickset hedge in the shortest possible time, they feed turkeys with the haws of the common white-thorn (*Cratægus Oxyacantha*), and then sow the stones which are ejected in their excrement, whereby they gain an entire year in the growth of the plant.‖ Birds, when they pluck cherries, sloes, and haws, fly away with them to some convenient place; and when they have devoured the fruit, drop the stone into the ground. Captain Cook, in his account of the volcanic island of Tanna, one of the New Hebrides, which he visited in his second voyage, makes the following interesting observation:—'Mr. Forster, in his botanical excursion this day, shot a pigeon, in the craw of which was a wild nutmeg.'¶ It is easy, therefore, to perceive that birds in their migra-

* Linnæus, Amœn. Acad., vol. ii. p. 409.

† Amœn. Acad., vol. iv. Essay 75. § 8.

‡ Amœn. Acad., vol. vi. § 22.

§ Smith's Introd. to Phys. and Syst. Botany, p. 304. 1807.

‖ This information was communicated to me by Professor Henslow, of Cambridge.

¶ Book iii. ch. iv.

tions to great distances, whether across land or sea, may transport even heavy seeds to new isles and continents.

The sudden deaths to which great numbers of frugivorous birds are annually exposed must not be omitted as auxiliary to the transportation of seeds to new habitations. When the sea retires from the shore, and leaves fruits and seeds on the beach, or in the mud of estuaries, it might, by the returning tide, wash them away again, or destroy them by long immersion; but when they are swallowed by land birds which frequent the sea-side, or by waders and water-fowl, they are often borne inland; and if the bird to whose crop they have been consigned is killed, they may be left to grow up far from the sea. Let such an accident happen but once in a century, or a thousand years, it will be sufficient to spread many of the plants from one continent to another; for in estimating the activity of these causes, we must not consider whether they act slowly in relation to the period of our observation, but in reference to the duration of species in general.

Let us trace the operation of this cause in connection with others. A tempestuous wind bears the seeds of a plant many miles through the air, and then delivers them to the ocean; the oceanic current drifts them to a distant continent; by the fall of the tide they become the food of numerous birds, and one of these is seized by a hawk or eagle, which, soaring across hill and dale to a place of retreat, leaves, after devouring its prey, the unpalatable seeds to spring up and flourish in a new soil.

Mr. Darwin found that fresh-water fish eat the seeds of many land and water plants, and as the same fish are often devoured by birds, such seeds may be readily transported by them to great distances. The same naturalist observed also that the earth adhering to the feet of birds often contains a variety of seeds of plants; and he mentions one case where from a ball of earth taken from the leg of a partridge he raised more than 80 individual plants belonging to species both of monocotyledons and dicotyledons.* Insects are probably instrumental like birds in disseminating plants, for

* Origin of Species, 4th edition, p. 432.

proofs have lately been obtained (see Chapter XLI.) of the germinating power of seeds swallowed by locusts and rejected in their dung.

The machinery above adverted to, is so capable of disseminating seeds over almost unbounded spaces, that were we more intimately acquainted with the economy of nature, we might probably explain nearly all the instances of plants inhabiting two points very remote from each other and not found in places intermediate; but some difficulties must remain in accounting for the range of species so long as the botanist confines his speculations to the present state of the earth's physical geography and climate. For the geologist can show that great changes have taken place in the height of the land and in the position of land and sea since the greater number of the living species of plants came into being. And we shall see in Chapter XLII. how much the rarity, or even the entire extinction, of species is promoted by these changes.

Agency of man in the dispersion of plants.—But in addition to all the agents already enumerated as instrumental in diffusing plants over the globe, we have still to consider man—one of the most important of all. He transports with him, into every region, the vegetables which he cultivates for his wants, and is the involuntary means of spreading a still greater number which are useless to him, or even noxious. 'When the introduction of cultivated plants,' says De Candolle, 'is of recent date, there is no difficulty in tracing their origin; but when it is of high antiquity, we are often ignorant of the true country of the plants on which we feed. No one contests the American origin of the maize or the potato; nor the origin, in the Old World, of the coffee-tree, and of wheat. But there are certain objects of culture, of very ancient date, between the tropics, such for example as the banana, of which the origin cannot be verified. Armies, in modern times, have been known to carry, in all directions, grain and cultivated vegetables from one extremity of Europe to the other; and thus have shown us how, in more ancient times, the conquests of Alexander, the distant expeditions of the Romans, and afterwards the Crusades, may

have transported many plants from one part of the world to the other.'*

But, besides the plants used in agriculture, the number which have been naturalised by accident, or which man has spread unintentionally, is considerable. One of our old authors, Josselyn, gives a catalogue of such plants as had, in his time, sprung up in the colony since the English planted and kept cattle in New England. They were two-and-twenty in number. The common nettle was the first which the settlers noticed; and the plantain was called by the Indians 'Englishman's foot,' as if it sprung from their footsteps.†

'We have introduced everywhere,' observes De Candolle, 'some weeds which grow among our various kinds of wheat, and which have been received, perhaps, originally from Asia along with them. Thus, together with the Barbary wheat, the inhabitants of the south of Europe have sown, for many ages, the plants of Algiers and Tunis. With the wools and cottons of the East, or of Barbary, there are often brought into France the grains of exotic plants, some of which naturalise themselves. Of this I will cite a striking example. There is, at the gate of Montpellier, a meadow set apart for drying foreign wool, *after it has been washed.* There hardly passes a year without foreign plants being found naturalised in this drying-ground. I have gathered there *Centaurea parviflora*, *Psoralea palæstina*, and *Hypericum crispum*.' This fact is not only illustrative of the aid which man lends inadvertently to the propagation of plants, but it also demonstrates the multiplicity of seeds which are borne about in the woolly and hairy coats of wild animals.

The same botanist mentions instances of plants naturalised in seaports by the ballast of ships; and several examples of others which have spread through Europe from botanical gardens, so as to have become more common than many indigenous species. Of these the water-thyme (*Anacharis alsinastrum*) is a striking example. Introduced into this country from America in 1841, it has spread so rapidly that

* De Candolle, Essai Elémen. &c. p. 50.

† Quarterly Review, vol. xxx. p. 8.

it has become a nuisance by overrunning ponds and ditches, and impeding the navigation of rivers and canals, in spite of all efforts to eradicate it.

It is scarcely a century, says Linnæus, since the Canadian *Erigeron*, or flea-bane, was brought from America to the botanical garden at Paris; and already the seeds have been carried by the winds so that it is diffused over France, the British Islands, Italy, Sicily, Holland, and Germany.* Several others are mentioned by the Swedish naturalist as having been dispersed by similar means. The common thorn-apple (*Datura Stramonium*), observes Willdenow, now grows as a noxious weed throughout all Europe, with the exception of Sweden, Lapland, and Russia. It came from the East Indies and Abyssinia to us, and was thus universally spread by certain quacks, who used its seeds as an emetic.† The same plant is now abundant throughout the greater part of the United States, along road-sides, and about farm-yards. The yellow monkey-flower, *Mimulus luteus*, a plant from the north-west region of America, has now established itself in various parts of England, and is spreading rapidly.

In hot and ill-cultivated countries, such naturalisations take place more easily. Thus the *Chenopodium ambrosioides*, sown by Mr. Burchell on a point of St. Helena, multiplied so fast in four years as to become one of the commonest weeds in the island, and it has maintained its ground ever since 1845.‡

The most remarkable proof, says De Candolle, of the extent to which man is unconsciously the instrument of dispersing and naturalising species, is found in the fact, that in New Holland, America, and the Cape of Good Hope, the European species exceed in number all the others which have come from any distant regions; so that, in this instance, the influence of man has surpassed that of all the other causes which tend to disperse plants over remote regions. About a fifth of the British flowering plants are supposed to be naturalised species, and a large proportion of them would perish with the discontinuance of agriculture.

* Essay on the Habitable Earth, Amœn. Acad; vol. ii. p. 409.

† Principles of Botany, p. 389.

‡ Ibid.

Although we are but slightly acquainted, as yet, with the extent of our instrumentality in naturalising species, yet the facts ascertained afford no small reason to suspect that the number which we introduce unintentionally exceeds all those transported by design. Nor is it unnatural to suppose that the functions, which the inferior beings extirpated by man once discharged in the economy of nature, should devolve upon the human race. If we drive many birds of passage from different countries, we are probably required to fulfil their office of carrying seeds, eggs of fish, insects, mollusks, and other creatures, to distant regions: if we extirpate quadrupeds we must replace them not merely as consumers of the animal and vegetable substances which they devoured, but as disseminators of plants, and of the inferior classes of the animal kingdom. I do not mean to insinuate that the very same changes which man brings about, would have taken place by means of the agency of other species, but merely that he supersedes a certain number of agents; and so far as he disperses plants unintentionally, or even against his will, his intervention is strictly analogous to that of the species so extirpated.

I may observe, moreover, that if, at former periods, the animals inhabiting any given district have been partially altered by the extinction of some species, and the introduction of others, a change must have taken place in regard to the particular plants conveyed about with them to foreign countries. As, for example, when one set of migratory birds is substituted for another, the countries from and to which seeds are transported are immediately changed. Vicissitudes, therefore, analogous to those which man has occasioned, may have previously attended the springing up of new relations between species in the vegetable and animal worlds.

It may also be remarked, that if man is the most active agent in enlarging, so also is he in circumscribing, the geographical boundaries of particular plants. He promotes the migration of some, he retards that of other species; so that, while in many respects he appears to be exerting his power to blend and confound the various provinces of indigenous

species, he is, in other ways, instrumental in obstructing the fusion into one group of the inhabitants of contiguous provinces.

Botanists are well aware that garden plants naturalise and diffuse themselves with great facility in comparatively unreclaimed countries, but spread themselves slowly and with difficulty in districts highly cultivated. There are many obvious causes for this difference: by drainage and culture the natural variety of stations is diminished, and those stray individuals by which the passage of a species from one fit station to another is effected, are no sooner detected by the agriculturist than they are uprooted as weeds. The large shrubs and trees, in particular, can scarcely ever escape observation, when they have attained a certain size, and will rarely fail to be cut down if unprofitable.

The same observations are applicable to the interchange of the insects, birds, and quadrupeds of two regions situated like those above alluded to. No beasts of prey are permitted to make their way across the intervening arable tracts. Many birds, and hundreds of insects, which would have found some palatable food amongst the various herbs and trees of the primeval wilderness, are unable to subsist on the olive, the vine, the wheat, and a few trees and grasses favoured by man. In addition, therefore, to his direct intervention, man, in this case, operates indirectly to impede the dissemination of plants, by intercepting the migration of animals, many of which would otherwise have been active in transporting seeds from one province to another.

We shall see in the sequel that species belonging to genera, previously foreign to the province into which they are introduced, often make their way more readily than plants of those genera and species which are indigenous, a fact which has a very important bearing on the theory of the origin of species. It is unfavourable to the doctrine that new species have been specially created in each station as best fitted of all possible organisms to flourish there, while it agrees perfectly with the view that new lands or stations are first colonised by such plants and animals as can gain access

to them without violating the fixed and immutable laws which govern the diffusion of species. Once introduced, they may become adapted by variation and selection to all the peculiar conditions of the new region; but they may still be less fitted for it than some other organisms which may coexist on the globe, and which may hitherto have been prevented by impassable barriers from reaching the same country so as to assert their superiority in the battle of life.

CHAPTER XLI.

INSULAR FLORAS AND FAUNAS CONSIDERED WITH REFERENCE TO THE ORIGIN OF SPECIES.

VOLCANIC ORIGIN AND MIOCENE AGE OF THE ATLANTIC ISLANDS—THEY HAVE NOT BEEN SINCE SUBMERGED, NOR UNITED WITH OTHER ISLANDS—ARGUMENTS AGAINST CONTINENTAL EXTENSION—MAP SHOWING THE GREAT DEPTH OF THE OCEAN BETWEEN THE VOLCANIC ARCHIPELAGOS OF THE NORTH ATLANTIC AND THE MAINLAND—SUBMARINE VOLCANIC ERUPTIONS OF THE PRESENT CENTURY—GENERAL INFERENCES TO BE DEDUCED FROM THE ENDEMIC AND OTHER SPECIES OF ANIMALS AND PLANTS IN THE ATLANTIC ISLANDS—FROM MAMMALIA—FROM BIRDS—FROM INSECTS——FROM PLANTS—FROM LANDSHELLS—SMALL NUMBER OF SPECIES OF LANDSHELLS COMMON TO MADEIRA AND PORTO SANTO—PROPORTION OF SPECIES COMMON TO MADEIRA AND THE DEZERTAS—CONTRAST OF THE TESTACEOUS FAUNA OF THE BRITISH ISLES AND THAT OF THE ATLANTIC ISLANDS—MODE IN WHICH AN OCEANIC ISLAND MIGHT BECOME PEOPLED WITH LANDSHELLS—VARIABILITY OF SPECIES NOT GREATER IN ISLANDS THAN ON CONTINENTS.

In the present chapter I shall consider the characteristic features of the fauna and flora of islands remote from continents. It has been truly said, that the distribution of species in such peculiar situations affords perhaps the severest test by which the theory of Variation and Natural Selection can be tried.

I have already stated that, as a general rule, when islands are near a continent, especially if they are only divided from it by a shallow sea, less, for example, than 100 fathoms in depth, their flora and fauna are identical with that of the mainland. But when an island, like Madagascar, is of large size, and is divided from the mainland by a deep channel of the sea several hundred miles wide, the species of quadrupeds differ from those on the continent, although nearly all the genera are the same, while of the other members of the animal and vegetable kingdoms there is a greater or less identity according to the class to which they belong.

If we then go a step farther, and contemplate small islands

far from land and surrounded by a deep ocean, we find that they are remarkable for the number of peculiar species of animals and plants which they contain, even a single island of the same group being sometimes inhabited by many species exclusively belonging to it. Yet even in such localities an affinity can be traced between the insular forms considered as a whole, and those of the nearest continent—a relationship exceeding that which connects them with the fauna and flora of more distant parts of the globe.

Volcanic origin and Miocene age of the Atlantic islands.—I shall refer chiefly to the Madeiras and Canaries as types of oceanic archipelagos, as I have myself visited them and studied their geological structure, without a knowledge of which the speculations and theories of a zoologist or botanist as to the mode in which they may have been peopled with living beings must necessarily be most imperfect. For in the first place we require information as to the period of the past to which the origin of the islands can be traced back, and then we have still to enquire whether they are fragments of a pre-existing continent, or were formed in mid-ocean by volcanic eruptions.

If we find evidence that in the case of these Atlantic islands the latter conclusion is true, we have still to learn whether each of them have continued above water during the whole course of its growth by successive eruptions, or whether it may have undergone oscillations of level, by alternate upheaval and subsidence. To most of these questions we are fortunately able to give satisfactory answers. It may be affirmed that the earliest eruptions took place in that part of the Middle Tertiary period which I have called Upper Miocene. As soon as the first solid lavas raised their heads above water, they were exposed to the action of the waves, and fragments of volcanic rocks were detached and rounded on the shore, and some of them swept into the adjoining depths of the sea, so as to form pebble beds, or conglomerates, or sands and sandstones, in which corals and shells of Miocene species were imbedded. By far the larger number of these species are now extinct. Their fossil remains have been rendered visible to us by their having been

uplifted in various islands to great heights, especially in the Grand Canary, Madeira, and Porto Santo, where they sometimes reach elevations of from 1,500 to 2,000 feet above the level of the sea. The movement of elevation was, I believe, very gradual, and went on during the whole period which witnessed the piling up on these islands of several thousand feet of basaltic and trachytic lavas, just as I have described the gradual rise of the Marine Pliocene strata, which constituted the foundations of Mount Etna, while the volcanic superstructure of the great cone was continually in progress.*

Nowhere could I detect, in any of the Atlantic islands which I visited, any signs of subsidence, or even of the temporary submergence of old terrestrial surfaces. In Madeira there are hundreds of thin horizontal layers of a red-brick colour, dividing those sheets of ancient lava which are seen in the sea-cliffs or in precipices in the interior. They exactly resemble a layer of burnt vegetable mould near Catania, already described (p. 13), as having been overflowed in the year 1669 by a great lava-current, and all of them seem clearly to be similar ancient soils formed by the decomposition of lava or volcanic sand. They bear testimony to the reiterated obliteration and renewal of old habitable surfaces, unaccompanied by any signs of submergence or the intervention of the sea. The movements of upheaval, on the other hand, seem to have been always partial and confined within the limits of the separate islands in which we find the marine strata uplifted. The 100 fathom line is always near to the shore,† and outside of this line the depth of water increases very rapidly, so that it is highly improbable that any of the principal islands were united and afterwards disjoined. Madeira would, indeed, be connected with the Dezertas,‡ if the sea was to sink 100 fathoms (600 feet); but there is no geological reason for presuming that the intervening ridge, over which there is, in one part, more than 400 feet of water, ever formed an unbroken isthmus joining Chão (see Map, fig. 143) to the south-eastern extremity of Madeira.

The great antiquity of the Canaries and Madeiras is at-

* Vol. ii. p. 5. † See Map, p. 409. ‡ See Map.

tested by the two-fold evidence of the height and magnitude of the islands themselves, and the age of the fossil organic remains (of Miocene date) already alluded to as having been imbedded in the products of early eruptions.

In Madeira the volcanic accumulations rise to the height of 5,000 feet, and in the Grand Canary to 6,000 feet. The

Fig. 143.

Map of the Madeiran Archipelago.

a. The Styx reef, 72 feet under water.
b. The Falcon reef, 26 feet under water.

highest crater in Teneriffe rises to an elevation of more than 12,000 feet above the sea-level. We know that violent eruptions are usually separated by long intervals of time; and from the history of the Canaries and volcanic archipelagos in general, we may infer that when one island is in a state of unusual volcanic activity, the other adjoining islands enjoy comparative repose. Moreover, in one and the same island, different sets of vents have been in eruption in succession; as,

for example, in Madeira, where the series of cones which now constitutes the highest and central ridge, is not the most ancient, for lavas proceeding from those vents, and flowing southwards, have overwhelmed the products of an older series of eruptions.*

Scarcely any progress has been made as yet in tracing in any of the archipelagos the passage from a Miocene to a recent fauna and flora by aid of fossil remains preserved in volcanic tuff; but Mr. Hartung and I were fortunate enough to discover in 1854 at San Jorge in Madeira, in a deep ravine at the height of 1,000 feet above the sea, a layer of lignite containing impressions of the leaves of forest trees and some ferns. They appear to belong to some part of the Pliocene period, and are certainly of great antiquity, for the numerous beds of lava and layers of volcanic ash piled over them are about 1,100 feet thick. Sir C. F. Bunbury, and after him Professor Heer, have shown that these fossil leaves prove Madeira to have been clothed, at the period when they were imbedded (possibly in the mud at the bottom of an old crater), with evergreens and other laurel-like trees, such as *Laurus* and *Oreodaphne* mixed with species of European genera, together with ferns, such as *Woodwardia*—in fact, with just such forests and such an undergrowth as we now find characteristic of the native vegetation of the island. Some of the species, however, according to Heer, differ from any now living in Madeira.†

It is a favourite opinion of some naturalists, and one advocated by Edward Forbes, that the Azores, Madeiras, and Canaries are the last remaining fragments of a continuous area of land, which once connected them with the West of Europe and North Africa. In order to explain my reasons for dissenting from this hypothesis, I may refer the reader to the adjoining map, partly based on a chart in Maury's Physical Geography of the Sea, and partly on Admiralty charts, for an analysis of which I am indebted to Mr. T. Saunders. A glance at this map will satisfy the reader that the theory of continental extension involves an amount of change of level

* See 'Lyell's Elements,' p. 639.

† See Bunbury, Geol. Quart. Journ., 1854, vol. x. p. 326, and 'Lyell's Elements,' 6th edit. p. 642, and 'Student's Elements,' p. 516.

so vast, that to assume its occurrence since the close of the Miocene epoch, is quite inconsistent with what we know of the constancy of the position of continents and oceanic basins throughout long geological periods. The Azores, in which the oldest fossiliferous rocks, like those of the Madeiras and Canaries, are of Upper Miocene date, are everywhere surrounded * by a zone of ocean more than 10,000 feet deep. There is, indeed, one line of soundings having a depth of more

Fig. 144.

Map, showing the depth of the ocean between the eastern volcanic archipelagos of the North Atlantic and the Mainland.

The ocean is tinted according to its depth, thus:

From the coastline to a depth of 1,000 feet *lightly*

From 1,000 feet to 10,000 feet . . *darker*

Below 10,000 feet . . *very darkly*

The lines of 1,000 feet are lettered *A.B.*, and the lines of 10,000 feet *C.D.*

than 15,000 feet between the Azores and Portugal, showing that a land communication would imply, first, the sinking of

* See Map.

a great continental area down to the sea-level, and then a further depression of the same from the sea-level to a depth of from 10,000 to 15,000 feet and upwards, all since the close of the Miocene period. The Madeiran archipelago, it will be seen, is near the line *CD*, which expresses a depth of 10,000 feet, and the same may be said of the western portion of the Canarian archipelago. On the eastern side of this last, the ocean has a depth of several thousand feet, dividing Fuertaventura and Lanzerote from the mainland. The general abruptness of the cliffs of all the Atlantic islands, coupled with the rapid deepening of the sea outside the 100 fathom line, are characters which favour the opinion that each island was formed separately by igneous eruptions in a sea of great depth. No geologist can doubt that the beds of lava and volcanic ash originally sloped down gradually towards the shore, and that the abrupt precipices now so general and often from 1,000 to 2,000 feet in almost perpendicular height facing the Atlantic, have been caused by the undermining action of the waves.

Submarine volcanic eruptions of the present century.—From what we know of the modern history of volcanic action in the basin of the Atlantic, we can be at no loss to conceive the manner in which such groups as the Azores or Canaries originated. I have already mentioned that the foundations of a future archipelago seem now in the act of being laid in the open ocean north-west of Ascension Island.* Here no less than 1,200 miles from the nearest part of Africa, unequivocal signs of submarine eruptions are occasionally witnessed. On this spot, so far out of sight of land, we may expect on some future day that a cone and crater will be built up as was Sabrina in 1811, in the sea off St. Michael's, one of the Azores, or as was Graham's Island, which in 1831 † rose up in a deep part of the Mediterranean, thirty miles from the nearest land, the south coast of Sicily. Although both these islands were gradually swept away by the waves, they have left reefs of solid rock in those parts of the sea from which, on some future occasion, a new volcanic cone may arise.

* See above, p. 64.

† See above, p. 60.

In November 1867 a submarine volcano burst out in the South Pacific at a point 1,200 geographical miles from New Zealand and 1,800 from Australia, between two of the most easterly islands of the Samoa or Navigator's Group, an archipelago where there had been no tradition of an eruption within the memory of man. This outburst was preceded by numerous shocks of earthquakes. Jets of mud and dense columns of volcanic sand and stones, rising 2,000 feet, and the fearful crash of masses of rock hurled upwards and coming in collision with others which were falling, attested the great volume of ejected matter, which accumulated in the bed of the ocean, although there was no permanent protrusion of a new volcano above its level.

General inferences to be deduced from the endemic and other species of animals and plants in the Atlantic Islands.—Whether therefore we consider the composition of the rocks and structure of the Atlantic islands, or their comparatively modern origin, or the vast depth and extent of the sea which separates them from the nearest continent, all these characters conspire to lead to the belief that they have been formed in mid-ocean by volcanic agency; and we shall find, if I mistake not, that the geographical distribution of the species, both of animals and plants, contained in them is far more in accordance with such an hypothesis than with that of continental extension. If, when the first islands were formed, the earliest colonists consisted of plants and animals which arrived as waifs and strays from the nearest land, they must have consisted of species which inhabited Europe and the North of Africa in Upper Miocene times. Fortunately we have made considerable progress in ascertaining what was the character of the fauna and flora of that epoch, differing widely as it did from that now existing in the same regions. We know, for example, that the Miocene flora of Europe had a strong generic affinity to the vegetation now characterising North America, much greater than to that of any other part of the globe in our own period; so that, if we find American forms in these Atlantic islands, it does not violate the general law that the animate creation in oceanic archipelagos bears always most resem-

blance to that of the nearest adjoining mainland, for these American forms are doubtless the remnants of a flora derived from an ancient and adjoining Miocene continent. But we must also remember that the Miocene fauna and flora of Europe gradually gave place to another of Pliocene date, and all these fluctuations in the animate world must have made themselves felt in the oceanic islands in which the successive destruction and renovation by volcanic action of the terrestrial surfaces would facilitate the settling in them of new species brought to them by the winds, marine currents, and various agents of transport, organic and inorganic. New sheets of lava would in particular weaken the barrier which preoccupancy opposes to new colonists; for the melted matter first annihilates every living thing over the strip of land, more or less broad, which extends from the volcanic orifice to the sea-coast, and then, after many years, when the lava has decomposed, it affords a fresh and virgin soil on which new immigrants may settle. Volcanic ejections and movements of upheaval, by causing perpetual variations in the surface-level of each island above the sea, would also promote fluctuations in the fauna and flora. That low portion of Africa which is marked in our map (fig. 144, p. 411), as the Sahara, was probably under water during the Miocene period. It is also possible that some volcanic islands may, during or since the Miocene era, have been formed and again destroyed within the area embraced in this map. They may have played an important part in promoting the interchange of species between different archipelagos, or between them and the continent.

It will be seen that at present, about half way between Madeira and the Canaries, there are some isolated rocks called the Salvages, which attain a height of 100 feet above the sea. The largest of them, which, like the rest, is uninhabited by man, is about a mile long. They rise from a deep ocean, and their steep cliffs show that they have been much reduced in size by the waves. The plants, insects, and land-shells found upon them belong in part to those peculiar types called 'Atlantic,' probably the relics of a Miocene fauna and flora.

The foregoing remarks on the geography and geology of the Atlantic islands are indispensable to a reader who would follow us in our speculations on the manner in which they may have become peopled with the animals and plants now inhabiting them. The absence or abundance of each class, the number of species common to the nearest continent, the range, whether limited or extensive, of each species through different islands or through different archipelagos, may throw light on the question whether species have been independently created, or whether they are modifications of pre-existing forms, the products of Variation and Natural Selection.

Mammalia.—The first great fact for which we have to account, is the entire absence of all indigenous Mammalia except bats. Palma, one of the Canaries, is inhabited by an indigenous bat, the progenitors of which may have migrated to that island in Miocene or Pliocene times.

When we have travelled over large and fertile islands, thirty miles or more in diameter, such as the Grand Canary and Teneriffe, and have seen how many domestic animals, such as camels, horses, asses, dogs, sheep and pigs, they now support, we cannot but feel amazed that not even the smaller wild animals, such as squirrels, field-mice, and weasels, should be met with in a wild state. The reader may ask how such quadrupeds could have reached an island like Madeira, more than 360 miles from the nearest mainland; but such a question at once implies the admission, that an arbitrary exertion of creative power does not give origin to Mammalia in every region where conditions favourable to their support may happen to exist.

It was long ago remarked by Dr. Prichard,* that among the various groups of fertile islands in the Pacific, no quadrupeds, with the exception of a few bats, have been met with, which might not be supposed, like the dog, the hog, and the rat, to have been conveyed thither from New Guinea by the natives in canoes. What is more extraordinary, even the large island of New Zealand, when first explored by Europeans, was found to be destitute of indigenous Mammalia,

* Prichard, Phys. Hist. of Mankind, vol. i. p. 75.

except one species of rat and two bats, said to be different from any found elsewhere. Bats have been seen wandering by day far over the Atlantic Ocean, and two North American species are known to visit the Bermudas at the distance of 600 miles from the mainland.* Mr. Darwin has therefore emphatically dwelt on the absence of Mammalia in islands far from continents, as strongly confirmatory of his theory of the origin of all species by descent from pre-existing closely allied species. The absence of Mammalia also supplies us with an argument against the doctrine of continental extension. Had a large tract of land stretching from Europe to the Atlantic islands been gradually submerged, so that at last no vestige of it remained above water, except the tops of certain volcanic mountains, the Mammalia would have retreated into such spots, for the smaller species at least might have found subsistence there. It has been suggested by the advocates of continental extension, that if Java should sink down several thousand feet, no land would be left except the summits of a series of lofty volcanic cones, round which there would be everywhere a deep ocean. But these same cones, as we have seen (p. 362), would each of them be inhabited by its peculiar Mydaus, and no doubt other species of Mammalia would take refuge there. Had any quadrupeds been able to swim to the Azores, Madeiras, or Canaries in the Miocene epoch, there is no ground for supposing that their descendants would not still survive; for, as before stated, each island seems during its whole growth to have afforded a habitable surface to terrestrial beings.

The rapid multiplication of goats when allowed to run wild in St. Helena, and of both goats and dogs in Juan Fernandez when introduced by the Spaniards, and of rabbits in Porto Santo, from a single brood imported there in 1418, proves the fitness of small islands to maintain wild quadrupeds, if they can once make their way into them.

The total dearth of Batrachians (frogs, toads, and newts), has also been pointed out by Darwin, as a characteristic of oceanic islands; yet he remarks that frogs, when taken to Madeira, the Azores, and Mauritius, have thriven to such a

* Origin of Species, p. 469; 6th edit. p. 351.

degree as to become a nuisance. If their spawn were carried down by a river to the sea, it would at once be destroyed by the salt water, as has been ascertained by experiment, and it is not of a nature to adhere to the feet of birds, as Mr. Darwin has found by observation.

A strong current which flows from the north, and passes between the Atlantic archipelagos and the mainland, may perhaps have prevented Mammalia and reptiles from reaching even the Canaries, one of which, Fuertaventura, is now only fifty miles from Africa, though possibly it was more distant when the Sahara was still under water. The same current may have prevented canoes from being drifted to Madeira, which is so isolated in mid-ocean, and on the shores of which no human being is believed to have ever landed until the year 1419. Madeira now supports a population of about 80,000 souls, and when we consider the great beauty and fertility of the island, and that it has existed ever since the Miocene epoch, we are not merely called upon to explain the absence of inferior animals, but why, if we adopt the theory of special creation, no race of mankind was formed expressly to inhabit such a paradise.

Birds.—For the same reason that bats, being provided with wings, form an exception to the general rule of the absence of Mammalia in oceanic islands, so we might expect that the feathered race would, of all classes of Vertebrata, be most fully represented. Accordingly we not only find this to be the case, but what is still more significant, as bearing on the theory of transmutation, almost all the birds in the Atlantic islands are absolutely identical in species with those of the nearest mainland. Thus in the Canaries and Madeiras, all the species except three or four are European. Of the 99 Madeiran species, there is only one peculiar to that island, and it is closely related to a European form; the other two non-European species are common to the Canaries. In the Azores, there are only two peculiar species, out of 51, and these two, a chaffinch and a bullfinch, are closely allied to European and North African birds.*

* Ibis, vol. ii. 1866, new series, p. 88.

We learn from Mr. Du Cane Godman, as before cited (p. 368), that every winter some birds are driven by violent gales over 1,000 miles of ocean from England to the Azores. The same observer informs us that the species are most numerous in the easternmost islands, and that the number diminishes rapidly as we examine those lying farther west, showing that the wearied and hungry voyagers drop down on the first land they discern. It is only by this frequent arrival of new-comers that we can explain the specific identity of the insular and continental fauna, the tendency to variation and indefinite divergence being checked in the manner explained at p. 322, by the absorption of the insular into the continental types, with which they are continually crossed. There are no American birds in the Azores, which cannot be entirely explained by the greater distance of that continent, because no less than sixty species are known to have crossed the Atlantic as stragglers, and to have reached the British Islands. The fact simply proves that strong winds blowing continuously in the right direction, are indispensable to enable birds to colonise remote islands.

The Bermudas, which are 700 miles from the coasts of America, are stocked with *species* all belonging to that continent. Of three European stragglers mentioned by Baird, two are common to Greenland, and may have come from the north, Newfoundland having served as an intermediate halting-place; and the third, our common skylark, a rare and occasional visitor, is so often carried in ships to America, that it may perhaps sometimes escape from a cage, and alight on the first land which presents itself.

The number of days for which land-birds can fast would more than suffice for their flight from Europe or even from America to the Azores. Mr. Bartlett informs me that a partridge sent from the London Zoological Gardens to the country remained accidentally in the box in which it was enclosed for five days without food or water; when discovered, it was alive, and being fed was soon restored to its usual vigour.

The birds of the volcanic archipelago of the Galapagos present in some respects a contrast to those of the Atlantic

islands; for although the distance from the nearest mainland is scarcely more than half that which separates the Azores from Europe, four-fifths of the land-birds are of species found nowhere else in the world. Out of twenty-six species, all but three or four are peculiar to these islands, at the same time that the whole of them are of South American types. What is still more worthy of note, several of these land-birds are peculiar to a single island of the group.* To explain this we may suppose that continuous gales have rarely blown from South America to the Galapagos since these islands first lifted their heads above the waves, and for this reason stragglers have only arrived after long intervals, some on one island and some on another. Once established, they have remained isolated, without communication with birds of the parent stock on the South American mainland, or with settlers of the same stock on other parts of the archipelago. On this subject Mr. Godman remarks, that while in the Azores, winds are constantly blowing from all points of the compass, so that land-birds are carried during storms from one island to another, in the Galapagos there are no such violent gales, but usually uninterrupted calms. He also adds, that while the marine currents in the Azores flow in varying directions, those of the Galapagos are strong, and always in the same direction. As to the web-footed birds or waders of the Galapagos, Mr. Darwin found that out of 11 species all except two consist of species common to the nearest continent.† This fact agrees well with the very wide range of this order of birds in all parts of the world, and is in accordance with their migratory habits. The relationship of the birds of the Atlantic islands to those of Europe and North Africa is nearly the same as that usually observed in a continuous continent. A few exceptional and peculiar types may in some cases have arisen from Variation and Natural Selection, since they first arrived, and some of them may perhaps be the descendants of Miocene species or genera which have died out in the mother continent.

Insects.—The insects of Madeira, the Salvages, and the

* Darwin, Origin of Species, p. 465. † Ibid.

Canaries, unlike the birds, exhibit a large proportion of indigenous species, and a great many genera peculiar to the Atlantic islands, represented in each separate archipelago by distinct species. Mr. T. V. Wollaston, in his 'Coleoptera Atlantidum,' has described no less than 1,449 species of beetles belonging to the three groups of islands above mentioned. Nearly all these have been collected by himself, and of the whole number more than 1,000 are of species hitherto unknown as inhabiting any other region, although there is no doubt that a great many of them will hereafter be discovered in lands bordering the Mediterranean. The distinctness of the fauna of different archipelagos is shown by the fact that out of 1,007 species obtained from the Canaries, and 661 from the Madeiras, only 238 are common to the two groups. Even of these it is suspected that the larger number have been introduced by man, and it is quite certain that 38 species have been so imported in very modern times.

Nearly every detached island adds some distinct species or marked variety to the general list, and one half of the 24 species found on the rocks called the Salvages, before mentioned, are peculiar, some of them belonging to those forms which have been called Atlantic types. 'If,' says Wollaston, 'we exclude those beetles which have probably been naturalised by human agency, there are marvellously few species which permeate the whole of the archipelagos, yet with few exceptions the genera are common to the whole.' Among the dominant forms the weevils, or *Curculionidæ*, preponderate greatly, and certain families of them are of essentially Atlantic types. No less than 50 species and varieties feed exclusively on the Euphorbias which are so abundant and diversified in form in the Canaries. Some fossil plants of the genus *Euphorbia* occur in the Miocene strata of Œninghen in Europe, and the parent stock both of these plants and of the Atlantic *Curculionidæ* may perhaps have been derived from the old Miocene continent. It has been already proved, by the researches of Heer and others, that the Miocene Coleopterous Fauna of Central Europe was actually richer than that now living in the same latitudes;* so that we

* 'Lyell's Elements of Geology,' p. 254; 'Student's Elements,' p. 198.

may well imagine that the various means of transport already alluded to (p. 382), by which insects are often carried seaward, may have been the means of introducing into the oceanic islands some of the progenitors of the present insular fauna.

The inferior facilities enjoyed by insects as compared to birds of crossing the sea, afford probably the true explanation of the marked difference in the relationship of the two faunas to that of the mother continent, and also of the comparatively small number of insects common to different islands of the same group. In proportion as the interchange of species is an event of rare occurrence, Variation and Natural Selection will be efficacious in forming distinct races in separate islands.

A recent examination of the beetles collected in the Azores by Mr. Godman, and described by Mr. Crotch,* shows that that archipelago presents phenomena analogous to those of the Canaries and Madeiras, although the proportion of Atlantic types is smaller, and the living European forms more predominant. This somewhat anomalous state of things may perhaps be accounted for by the fact, that although the Azores are so much farther from Europe than Madeira and the Canaries, yet they are situated in a much stormier latitude, and thus receive waifs and strays more frequently.

Plants.—Dr. Hooker, in his admirable essay on Insular Floras,† remarks that in Madeira, besides the numerous cultivated plants which have been introduced by man, and the poppies, fumitories, groundsels, and other weeds which he has brought with him unintentionally, there are other native varieties of European species, and sometimes representative genera, which indicate a relationship to the nearest continent. He also observes that whereas we find on ascending mountains in Great Britain or on the continent of Europe, from the height of 2,000 feet and upwards, species proper to more northern latitudes, and differing from those flourishing at lower levels, we do not meet with any

* Azorean Coleoptera, Zool. Proc. 1867; pt. ii. p. 349.

† Lecture to Brit. Assoc. Nottingham, 1866; Gardener's Chronicle, 1867

such boreal forms in Madeira even at the height of 4,000 feet. The species become fewer as we ascend, but they continue to be the same as those which flourish at inferior elevations. Had the theory of continental extension been true, we might have expected the Atlantic islands to have borrowed their upland flora from higher latitudes during the Glacial period.

A botanist, wholly ignorant of the plants which lived on the continent of Europe in Miocene times when the first volcanos were beginning their eruptions in the Canaries, Madeiras, and Azores, would be in no small degree perplexed at the presence in these archipelagos of such Atlantic types as Clethra and Persea, of which living representatives exist in no part of the world nearer than the continent of North America. It would seem to be a violation of the general law according to which the organic productions of islands bear most resemblance to those of the nearest continent. But fortunately the labours of Unger, Heer, and Göppert on the fossil botany of the Tertiary strata have shown us that Europe, when the Atlantic volcanos first reared their crests above the waves, was covered with an exceedingly rich vegetation.

No less than 900 species of these fossil plants have been detected in the strata of a single locality at Œninghen in Switzerland.* The most conspicuous feature, says Heer, in this ancient flora, is the large number of genera of plants now peculiar to America; whereas those having European affinities only hold the second rank, those of Asia the third, of Africa the fourth, and those of Australia the fifth. Among the prevailing American forms are Clethra and Persea, above alluded to, genera common to Madeira, the Canaries, and Azores. Regarded as relics of a Miocene flora, they are just such forms as we should naturally expect to have come from the adjoining Miocene continent. Another plant of a singularly aberrant form, and which we may well imagine to be the last survivor of a Miocene type, is the *Monizia edulis*, belonging to a genus which has now no representative else-

* For a brief sketch of the Miocene flora and fauna, see 'Lyell's Elements,' 6th ed. chap. xv.; and 'Student's Elements,' p. 186 et seq.

where in the world. This conspicuous shrub is an umbelliferous plant with a stem like an inverted elephant's trunk, crowned with a huge tuft of parsley-like foliage. A fine specimen of it may now (1867) be seen growing in the greenhouse of the Botanical Garden at Kew. It is peculiar to one of the rocky islands of the Dezertas,* where it probably owes its preservation to the exceptional conditions which it has there enjoyed cut off from all communication with other islands, into which new colonists, both of the animal and vegetable worlds, have been able more freely to penetrate.

Dr. Hooker reminds us that the extinction of so many species and of some genera which flourished in the Miocene period in Europe, is fully accounted for by the great change of climate which the temperate latitudes of the northern hemisphere experienced in Pliocene and Glacial times. The old subtropical species, which had long flourished in Central Europe and in the regions bordering the Mediterranean, gave way before a more northern flora, but many plants and not a few of the insects, which were extirpated on the continent, may well have survived in oceanic islands which enjoyed a milder and more equable temperature. To this source we may probably refer those peculiar 'Atlantic types' above alluded to, which pervade all the archipelagos. We are informed by Dr. Hooker that the seeds of the West Indian bean-like climber Entada were floated to the Azores 3,000 miles by the Gulf-stream. These seeds, after such long immersion in salt water, although they could not stand the climate of the Azores, germinated in the Garden at Kew; from which fact we learn how easily seeds of the Miocene period may have been carried uninjured by currents from the Mediterranean region to any one of the Atlantic islands, as none of them are so far from Europe as are the Azores from the West Indies. But it is probably to birds more than to marine currents that new islands owe the plants which clothe them. We have already seen (p. 394) how many seeds which have been swallowed by birds and ejected in their dung, germinate freely, and these, if carried by a land-bird driven to a new volcanic island,

* See Map, fig. 143, p. 409.

would soon cover the unoccupied ground, until other species brought by a similar mode of transport came to dispute their monopoly.

It is not easy to conjecture how many different modes of transport nature may have employed in peopling some Atlantic islands. Even icebergs may have played their part in carrying plants to the Azores in the Glacial period, for they are now sometimes floated to latitudes farther south than that archipelago, as we have already stated (Vol. I. p. 249). Mr. Hartung found fragments of rock in the Azores which he regarded as erratics of iceborne origin. When, indeed, we consider all the changes in climate, and in the direction of winds and currents, and in the species of birds which have occurred in the lapse of millions of years since the Miocene epoch, to say nothing of the incessant transformations undergone by the volcanic islands themselves, we must feel that the colonisation of the several archipelagos has been the result of such a complexity of causes and conditions, that the distribution of species is not more anomalous or capricious in its character than we might reasonably have anticipated. If we find a plant or animal peculiar to a single island, we may suppose it to have been first brought there as a straggler from the adjoining continent, and it may never have been able to spread to any other island; or it may have had a wider range until dispossessed of most of its former stations by new intruders, or by volcanic eruptions; or lastly, the parent stock may still flourish in some one of the islands or archipelagos, but the descendants may have gone on diverging from the original type, until, in the lapse of thousands of generations, the amount of difference may be of specific value. When it is said that the Atlantic types, whether of plants or insects, are common to the Azores, Madeiras, and Canaries, it is only the genera which are spoken of, for the species are almost always distinct in each archipelago.

Mr. Darwin had said in his 'Origin of Species,' that we probably still remain ignorant of many means of transoceanic migration which will one day be discovered. These anticipations have been singularly verified even since 1866, when

this opinion was advanced in the fourth edition of his celebrated work.* Some singular illustrations of the truth of this opinion have since been obtained. Hearing that many new plants had been observed to spring up in Southern Africa in districts which had been invaded by locusts, Mr. Darwin procured from a correspondent, Mr. Weale, residing in Natal, a small packet of dry locust dung, weighing less than half an ounce. Seeds were extracted from the middle of several pellets, and their true nature ascertained by dissection, and others were sown, which when they had germinated, produced no less than seven individuals belonging to at least two kinds of grasses. A locust of the migratory species blown from the coast of Africa was taken on one occasion by Mr. Darwin himself when at sea, at a distance of 370 miles from the nearest land, or somewhat farther than is Madeira from Africa. The same naturalist observed in 1867 some mud adhering firmly to the foot of a woodcock, which weighed when dry nine grains. He extracted from it the seed of the *Juncus bufoni*, which germinated. This fact throws much light on the colonisation of new islands by plants, for of all families even of wading birds the woodcocks are perhaps the most migratory, and there is scarcely a remote island which they do not sometimes reach.

Mr. Lowe informs me that when he was in Madeira in 1844 he witnessed the arrival at Funchal of a flight of locusts, which came probably from Africa. For three days they whirled slowly in a circle or ellipse of about five miles diameter round the town, alighting on the trees at night and continuing their flight by day. They do not seem to have consumed much of the vegetation, and when caught appeared torpid and inactive. Their length was about three inches, and they were as numerous as the flakes of snow in a snowstorm, a telescope directed upwards not enabling the eye to reach the upper limits of the swarm. After two or three days they disappeared, and vast shoals of them were seen afterwards floating on the surface of the sea. It is remarkable that they made no permanent settlement upon

* Chap. xi. 4th ed. p. 433. 1866.

the island, the locust not being one of the Madeiran insects, nor is it known that they introduced any new plants in their dung; but as probably more than one migratory swarm has visited the island again and again, perhaps at distant intervals since it originated, some of the species of the insular flora may have been derived from this source.

When we compare the flora of any one of the Atlantic archipelagos—that of the Madeiras for example—with that of the British Islands, the difference in the number of indigenous species and in the proportion of plants common to the nearest continent is truly marvellous. In the Madeiras there are hundreds of indigenous species, although the entire flora is not half so numerous as the British, while, on the other hand, all the British plants are species common to the continent of Europe, except two, the *Spiranthes gemmipara*, which occurs on the north-west side of Bantry Bay in Ireland, and is found nowhere else on this side of the Atlantic, and a North American water-plant, *Eriocaulon septangulare*.

Landshells.—I have reserved to the last my comments on the landshells, as their geographical distribution in the Atlantic islands is more singular and instructive than that of any other class of living beings. In the Madeiran archipelago especially, as was long ago pointed out by the Rev. R. T. Lowe, every island has its distinct species, and the whole fauna differs almost entirely from that of Europe and Africa. Moreover, it is when we contemplate these air-breathing mollusks that we find the contrast between the Atlantic and British islands to have reached its climax; for in Great Britain no one of the different islands is characterised by peculiar species, and the insular and adjoining continental faunas are the same.

Mr. Lowe, in the year 1834, described 71 species of landshells of the genera *Helix*, *Bulimus*, *Achatina*, &c., from the Madeiran archipelago, 44 of which were new. He then stated that but few of these were common to the Canaries, and, what was still more astonishing, only two were common to the islands of Madeira and Porto Santo, divided by a sea only 30 miles wide. Since his memoir was published his own further investigations, and those of Mr. Wollaston

and others, have augmented the list of species, and taught us that some few of those before known had a wider range than was at first supposed; but notwithstanding these additions to our knowledge, the general conclusions announced in 1834 hold good, or are even rendered more striking. The instruction derived from this fauna is greatly enhanced by the occurrence, both in Madeira and in Porto Santo, of large assemblages of fossil shells which reveal to us the state of this part of the animal creation in the Newer Pliocene period. Some few of the fossil species are extinct, but most of them are the same as those now inhabiting Madeira and Porto Santo respectively; consequently the two ancient groups of shells are as dissimilar as are the two recent ones. From this we learn that in the Newer Pliocene period the two islands must have been disjoined, as they are now. It is also clear that at that period neither island was united with the continent of Europe; for scarcely any of the fossil species are European, and the absence of these confirms the general opinion of naturalists that almost all the species now living in this archipelago and common to the continent have been introduced by man since the beginning of the fifteenth century. During my short stay in Madeira there were found in the earth of a single flower-pot in which a garden plant had been sent from Lisbon no less than three species of Portuguese snails (Helices), showing us how unconsciously the horticulturist is busied in alloying the purity of the native fauna. Most of the European shells have been found in the gardens of Funchal, from which principal town as from a centre they radiate for greater or less distances.

At the time of my visit in 1854 the known living species of Madeira proper, excluding the modern intruders above alluded to, amounted to 56, and those of Porto Santo to 42; only 12 of the whole being common to both islands; and, what is of no small significance, even some of these 12 being represented in the two islands by distinct varieties. In truth, the discordance is more like that of two of the six great zoological provinces of the globe before described (p. 337), than of two islands of the same province in sight of each other.

If we then refer to the fossil groups, we find 36 species in Madeira and 35 in Porto Santo, only 8 being common to the two islands, and 5 of these 8 being represented by distinct varieties in each island respectively. It was to be expected that as Porto Santo is much less cultivated than Madeira, and has only a small human population, the fossil and living species should agree much more with each other than do those of Madeira; and the fact that they do so encourages us to reject as spurious or as modern interlopers those landshells now living in Madeira which are missing in the fossil group of that island. The fossils occur at Caniçal near the eastern extremity of Madeira,* in prodigious numbers, imbedded in a superficial deposit of calcareous sand and mud. Among the most common is a conspicuous species of an unusual form named *Helix delphinula* (from its resemblance to the marine genus *Delphinula*), which has entirely disappeared from the Atlantic islands. Another smaller but very characteristic shell, *Helix tiarella*, must have swarmed in the Newer Pliocene period, but it has now become so extremely rare that for a long time it was supposed to be extinct, until a few surviving individuals were detected by Mr. Wollaston, in 1855, at a great height on some precipitous and nearly inaccessible rocks in the interior of Madeira. Two species of Achatina and two of Pupa, also fossil at Caniçal, are supposed to have disappeared from the living creation, but as they are of small dimensions they may possibly have been overlooked, although, if extant, they must have become very scarce.

In the shelly sand of Porto Santo a conspicuous shell, *Helix Lowei*, is very abundant. It is of so large a size that it could hardly have escaped detection if it still existed on either of the principal islands, but lately a few individuals of this species have been detected on the rock called Ilheo di Cima off Porto Santo.† By some conchologists *Helix Lowei* is regarded as a gigantic variety of the living *H. Porto sanctana*, which also occurs fossil in the same sands. If this opinion be correct, it offers by no means the only example in

* See Map, fig. 143, p. 409. † Ibid.

the fauna of this archipelago of the same distinct races being found both fossil and recent, and in both cases without any intermediate varieties. One of the two forms may possibly represent the parent stock, and the other the extreme of divergence. There must once have existed, according to the theory of Natural Selection, all the transitional forms between the two extremes. But these forms may have died out for want of favourable conditions, or may have been absorbed into one or other of the extremes, which last may be able to maintain their ground on the principle before alluded to (p. 320), according to which more plants or animals find support in a limited area if they are of many different genera than if they all belong to one genus. There are however in the Madeiran archipelago some polymorphous species, such as *Helix polymorpha*, in which the transitional links between the extremes are not missing, and they remind us of the varieties of the English brambles and roses; but such cases are the exception to the rule, for reasons to be explained in the next chapter.

I have alluded to *Helix tiarella* in Madeira; an allied representative of the same peculiar form, *H. coronata*, abounds in a fossil state in Porto Santo, and is also still living in that island, though it is rare. Another, or third closely allied species, *H. coronula*, was first found fossil in Bugio, one of the Dezertas, and it probably still exists on some part of those inaccessible rocks, for a few living individuals have lately been found on the nearest adjoining coast of Madeira. They may supply an example of the smaller island having yielded one of its indigenous species to Madeira; for the absence of this shell among the fossils of Caniçal seems to imply that it has only recently gained access to Madeira proper. These three distinct though kindred forms of a peculiar division of the Helicidæ belonging to Madeira, Porto Santo, and the Dezertas remind us of the representative species of some genera found in Asia, Europe, and America.

Having alluded to the Dezertas, I may add that 19 species of landshells have been found on them, 12 of which, or about two-thirds of the whole, are common to Madeira, and only 5 to Porto Santo. The nearer affinity of the fauna to

Madeira was to be expected, not only because of its greater proximity, but because, as will be seen by our map, Madeira and the Dezertas stand within the same 100 fathom line, and the channel between them may once have been narrower, although there is no reason for believing that the land was ever continuous, or even that Chão, Dezerta Grande, and Bugio were ever united; for each of these rocks has some species of shells as well as some varieties peculiar to itself. It is worth remarking, as showing the limited range of species when the whole archipelago is considered, that there are only two species of landshells common to all the three faunas of Madeira, the Dezertas, and Porto Santo.

The antiquity of the fossils of Madeira and Porto Santo is unmistakable, although they are more modern than the newest lava streams; for to say nothing of the time required to annihilate several species and greatly to alter the relative numbers of others, there are proofs of local geographical changes of subsequent date. Since the accumulation of the volcanic sand and mud, in which the landshells are enveloped, there has been much undermining of the sea-cliffs, both in the narrow promontory in which Caniçal is situated and on the northern coast of Porto Santo. Some of the shelly formation of the last-mentioned island consists of sand-dunes which have been cut off abruptly in the vertical cliffs, and must once have extended farther in a seaward direction. The whole island, indeed, of Porto Santo has suffered great denudation, and some rocks indicated by the letters *a b* in our map (p. 409), one of them called the Falcon, now covered by only 26 feet of water, and the other the Styx by 72 feet, may perhaps mark the site of isolated volcanic cones which once rose above the sea-level. But that the whole space within the 100 fathom line* was ever continuous land, I think improbable. Such an extension would give to Porto Santo five times its present dimensions. The proportion of extinct species as compared to the living ones in Madeira and Porto Santo is about 8 per cent., which may perhaps be slightly diminished by the future discovery of

* See Map, fig. 143, p. 409.

some of the smaller species; but the real discordance between the ancient and modern fauna will never disappear, for it is even greater than is expressed by the numerical statements above given, some species formerly most dominant being now very feebly represented, and some fossil races as well as species having become extinct.

The landshells of the Canaries, when we exclude those which have probably been introduced by man, are very distinct from those of Madeira. The different islands in the Canaries have more species in common than the Madeiras, but this fusion may be partly owing to the remote and unknown period at which the aboriginal inhabitants, the Guanchos, settled there.

Contrast of the testaceous fauna of the British isles and that of the Atlantic islands.—I shall now revert to the extraordinary contrast between the distribution of landshells in the Atlantic and British islands. If a curved line be drawn from the Azores through Madeira to the Canaries, its length would be about 750 miles, or about equal to a line drawn from the Shetland islands through Scotland and England to the Scilly islands. The British archipelago contains more than 200 inhabited islands, when we include the Shetlands, Orkneys, Hebrides, and others. In all of these the landshells are the same, whereas in the Atlantic archipelagos it is not only the principal or habitable islands, but almost every uninhabited rock off the coast, which supplies the conchologist with peculiar species or varieties. In the British area, it would seem at first sight, as if the land-snails had never had any difficulty in crossing the sea, whereas in the Atlantic archipelagos the narrowest marine channels have formed in most cases impassable barriers. The Scilly islands are as far from Cornwall as is Madeira from Porto Santo, yet in them the conchologist obtains no distinct species, nor even any marked races, whereas, on crossing from Madeira to Porto Santo, he finds four-fifths of the species different, besides some peculiar races, even of those shells which are common to the two sides of the channel. It may, no doubt, be said that the southern parts of England display a richer fauna, and contain certain species (about eight), which do not range

farther northwards than Yorkshire. These are: *Helix pomatia*, *H. carthusiana*, *H. revelata*, *H. Pisana*, *H. obvoluta*, *Bulimus montanus*, *Clausilia Rolphii*, and *C. biplicata*. It is more difficult to name species which are peculiar to the north, *Vertigo alpestris* affording perhaps a solitary example.*

In what manner, then, can we explain or refer to one and the same law of distribution the apparently incongruous phenomena exhibited in the two regions above compared? Some zoologists who have been struck with the unusual number of endemic species and marked varieties observed in oceanic islands, have suggested that the terrestrial mollusca must be more variable than other classes of the animal kingdom. But this idea is wholly inadmissible, for we need go no farther than the fossil faunas of Madeira and Porto Santo, above alluded to, to prove the remarkable constancy and persistency of form of the genera *Helix*, *Pupa*, *Achatina*, and *Clausilia*, from the Newer Pliocene era to our own times. To solve the enigma we must appeal to the immense difference in the lapse of time, during which the islands of the British and those of the Atlantic archipelagos have remained separate from each other and from the nearest continents. In the one case there has been everywhere a land communication between every part of the archipelago since the commencement of the Glacial period, when the species of marine and terrestrial testacea were everywhere the same as they are now; in the other there has been no land communication since the Miocene epoch, when the whole fauna and flora of the globe bore but a distant resemblance to those now established. Our map (p. 409) will satisfy the reader, that if the bed of the Atlantic were everywhere uplifted 100 fathoms, all the principal archipelagos and islands would remain as disconnected as they are now, whereas we know that a similar upward movement would unite every one of the 200 British islands with each other and with the continent.† Indeed, nearly all of them would be joined to the mainland and to each other with a change of level of less than 400 feet. That there have been great

* See Mr. J. Gwyn Jeffreys, British Conchology, 1866–67.

† See 'Antiquity of Man,' by the author, Map, fig. 41, p. 279.

movements of oscillation in the British area since the Glacial period is proved by independent geological evidence, whereas there are no signs, as before stated, of any general movements of like magnitude in the Atlantic area, but only here and there some evidence of partial upheaval.

I have already remarked that had Porto Santo been united with Madeira proper in the Newer Pliocene period, the two fossil faunas would have been fused together, instead of being as different as are the living native shells of the two islands. In Great Britain, also, we have a fossil fauna of terrestrial shells associated with the bones of the Mammoth and other extinct mammalia in ancient drift; and this enables us to carry back the comparison of the Atlantic and British archipelagos one step farther. We recognise in the British fossils the same uniformity, or wide range of species, as in the actual or recent fauna. No less than 48 species of fossil landshells were collected by the late Mr. John Brown from the Post-Pliocene drift of Copford in Essex, and with the exception of two Helices (which still survive on the continent), all are of living British species. But if England had been submerged a few hundred feet, and divided into islands, even since the Pliocene period, we might have expected the shells associated with extinct quadrupeds in different counties to display some marked want of agreement in species and varieties. There is however no such contrast. If, for example, we compare the landshells of the Wiltshire drift, near Salisbury, of the age of the Mammoth, with those of Essex before mentioned, places twice as far apart as are Madeira and Porto Santo, they exhibit no difference whatever in the species of fossil landshells. From this fact we may infer that, although the British area has been partially submerged since the commencement of the Glacial period, yet its normal state has been a continental one.

Mode in which an oceanic island might become peopled with landshells.—The reader may well ask, if Madeira and Porto Santo have made so little progress in interchanging their respective species of landshells in the course of that vast lapse of ages which has occurred since the Newer Pliocene period, how could any of the Atlantic archipelagos ever have

become peopled by migration from Europe or Africa? The enigma is certainly perplexing, and we must assume that the arrival of landshells, as waifs and strays from a continent, is an exceedingly rare event. It has been suggested that birds may transport across the sea the eggs of these mollusks in mud attached to their feet. But if so, why have the birds which fly freely across the channel, only 30 miles wide, between Madeira and Porto Santo, allowed the fauna of these two islands to remain so distinct? or why have those birds which arrive every year from the continent in the Atlantic islands introduced so few landshells? Hitherto the naturalist has not witnessed the arrival of a new continental Helix on any remote oceanic island, except by the aid of man; and to those who are unwilling to abandon in despair all hope of solving the problem, it is satisfactory that such should be the case. How inexplicable for example would be the dearth of land quadrupeds in the Atlantic islands if some members of this class were seen occasionally to swim across the ocean from Europe to the Azores!

If hereafter we should discover the mode in which air-breathing mollusks can sometimes traverse a wide expanse of ocean, we may be sure that the occasions of transport will be few and far between, so that a continental species when it colonises a new island has time to vary and to give rise to one or two new races, before other representatives of the original continental type follow in the same direction, so as to cross with the first settlers and check divergence.

If floating timber, or land-birds, or insects, or any other causes organic or inorganic, serve as the means of transport, their agency must be so casual and irregular as to cause the results to appear capricious in the extreme.

The first Miocene Helix which reached Madeira may have been of a different species from the first which reached Porto Santo. It has been imagined that *Helix inflexa* Martens, an extinct Miocene form of Europe, may have been the parent stock of *H. portosanctana*, of which the gigantic *H. Lowei* may be a variety, but the last-mentioned form seems never to have reached Madeira. The extinct *H. Raymondi*, so common in the French Faluns or Upper Miocene strata, is supposed

to have been the ancestral type of another common shell, *H. Bowditchiana* Pfeiffer, found both fossil and recent in Madeira and Porto Santo.

Let us assume that certain Miocene species, nearly all of them long since extinct, were carried as waifs and strays to separate islands by a concurrence of circumstances so rare as to happen once only in several hundred thousand years, other combinations of circumstances almost equally rare might be required to convey a species from one island to another. A volcanic eruption, for example, which might only occur once in the whole course of the building up of an archipelago, at exactly the same season of the year, or at the same height above the sea, with equal violence and when the wind or marine currents were in the same direction. Such a convulsion might cause the dispersion of some Helices from one part of an archipelago to another in a manner altogether without parallel during the antecedent or subsequent history of the same region. If the reader will refer to our description of the birth of Monte Nuovo, Vol. I. p. 608, near Naples, in 1538, he will see that while many land-birds were killed, those which escaped and flew terrified from the scene of the catastrophe, must, like the human inhabitants, have been covered with mud which was showered down so as to envelope all things. In the beginning of such an eruption, trees, shrubs, and vegetable soil, in which the eggs of landshells must sometimes be included, would be hurled up into the air by the aqueous vapour. The eggs of a pupa are sometimes so minute and their terminal velocity in air so slight that they might be carried many miles by the wind before alighting on the ground—as far perhaps as from Madeira to the Dezertas. There is no reason for supposing that the tendency of species to form new varieties is greater in an oceanic island than on a continent. But if islands be separated from each other throughout so long a period as would be sufficient on the continent to change most of the species, then it is evident that there will be a greater manufacture of new species in the islands. Let us suppose a band of emigrants to have gone from some European country a thousand years ago and to have formed colonies in the Azores,

Canaries, and Madeiras, and that all communication between them and the mother country and between the different archipelagos was cut off for a thousand years, there would then be in all probability four languages spoken between the mother country and her three colonies all different from the original tongue of the ninth century. The population of the three archipelagos, like the area of land formed by the whole of them, might be very insignificant compared with that of the country from which the first emigrants proceeded, yet the smaller number of islanders, in consequence of their isolation, would have given rise to three new languages, and the inhabitants of the continent to one only. Not that the invention of new terms and idioms or the disuse of old ones would have gone on at a greater rate in the islands, but because each archipelago being separated from every other one and from the rest of the world, had formed an independent linguistic centre. In like manner the distinctness of the landshells in the Canaries, Madeiras, and Azores, and in many of the separate islands of each, are the results of the prolonged isolation of small fragments of land in mid-ocean, not of a greater tendency in the testacea inhabiting such islands to vary.

In conclusion I may observe, that the extent to which the species of mammalia, birds, insects, landshells, and plants, (whether flowering or cryptogamous,) agree with continental species, or the degree in which those of different archipelagos or of different islands of the same group agree with each other, has an unmistakeable relation to the known facilities enjoyed by each class of crossing the ocean. Such a relationship accords well with the theory of Variation and Natural Selection, but with no other hypothesis yet suggested for explaining the origin of species.

CHAPTER XLII.

EXTINCTION OF SPECIES.

CONDITIONS WHICH ENABLE EACH SPECIES OF PLANT TO MAINTAIN ITS GROUND AGAINST OTHERS—EQUILIBRIUM IN THE NUMBER OF SPECIES, HOW PRESERVED—AGENCY OF INSECTS IN PRESERVING THIS EQUILIBRIUM—DEVASTATIONS CAUSED BY LOCUSTS—EFFECT OF OMNIVOROUS ANIMALS IN PRESERVING THE EQUILIBRIUM OF SPECIES—RECIPROCAL INFLUENCE OF AQUATIC AND TERRESTRIAL SPECIES—HOW CHANGES IN PHYSICAL GEOGRAPHY AFFECT THE DISTRIBUTION OF SPECIES—EXTENSION OF THE RANGE OF ONE SPECIES ALTERS THAT OF OTHERS—SUPPOSED EFFECTS OF THE FIRST ENTRANCE OF THE POLAR BEAR INTO ICELAND—INCREASE OF REIN-DEER IMPORTED INTO ICELAND—INFLUENCE OF MAN IN DERANGING THE NUMERICAL STRENGTH OF SPECIES—INDIGENOUS QUADRUPEDS AND BIRDS EXTIRPATED IN GREAT BRITAIN—EXTINCTION OF THE DODO—RAPID PROPAGATION OF DOMESTIC QUADRUPEDS OVER THE AMERICAN CONTINENT—POWER OF EXTERMINATING SPECIES NO PREROGATIVE OF MAN—CONCLUDING REMARKS ON EXTINCTION.

Conditions which enable each species of plant to maintain its ground against others.—I propose in this chapter to treat of the various causes to which the continual extinction of species, both in the animal and vegetable creation, is due.

Every naturalist is familiar with the fact, that although in a particular country, such as Great Britain, there may be more than 3,000 species of plants, 12,000 insects, and a great variety in each of the other classes; yet there will not be more than 100, perhaps not half that number, inhabiting any given locality. There may be no want of space in the supposed limited area: it may be a large mountain, or an extensive moor, or a great river-plain, containing room enough for individuals of every species in our island; yet the spot will be occupied by a few to the exclusion of many, and these few are enabled, throughout long periods, to maintain their ground successfully against every intruder, notwithstanding the facilities which species enjoy, by virtue of those powers of

diffusion already mentioned (Chapters xxxviii., xxxix., xl.), of invading adjacent territories.

The principal causes which enable a certain assemblage of plants thus to maintain their ground against all others depend, as is well known, on the relations between the physiological nature of each species, and the climate, exposure, soil, and other physical conditions of the locality, and the power of each to compete with other organic beings in the struggle for life. Some plants live only on rocks, others in meadows, a third class in marshes. Of the latter, some delight in a fresh-water morass,—others in salt marshes, where their roots may copiously absorb saline particles. Some prefer an alpine region in a warm latitude, where, during the heat of summer, they are constantly irrigated by the cool waters of melting snows. To others loose sand, so fatal to the generality of species, affords the most proper station. The *Carex arenaria* and the *Elymus arenarius* acquire their full vigour on a sandy dune, obtaining an ascendency over the very plants which in a stiff clay would immediately stifle them.

Where the soil of a district is of so peculiar a nature that it is extremely favourable to certain species, and agrees ill with every other, the former get exclusive possession of the ground, and as in the case of heaths, live in societies. In like manner the bog moss (*Sphagnum*) is fully developed in peaty swamps, and becomes, like the heath, in the language of botanists, a social plant. Such monopolies, however, are not common, for they are checked by various causes. Not only are many species endowed with equal powers to obtain and keep possession of similar stations, but the same spot of ground may for various reasons be more fit to support a new species than one which has long lived upon it. Oaks, for example, render the soil more fertile for the fir tribe, because the oak having spread its roots deeply and widely, leaves the soil near the surface in a practically virgin state, so that when by some cause, as a hurricane or a fire, the oak is destroyed, the young fir, whose small roots do not penetrate far below the surface, would, if its seeds were present and ready to germinate, find the soil fresh, and fitted for its nourishment.

So also any change of conditions, such as the submergence of a district, and its conversion into a marsh, or the destruction of an ancient forest by a hurricane, by causing heat, light, currents of air, moisture, or other influences to be felt for the first time in certain spots or districts, would naturally give an opportunity to new plants to establish themselves, and many generations might pass away before the original occupiers of the soil could again obtain possession of it.

Equilibrium in the number of species, how preserved.—'All the plants of a given country,' says De Candolle, in his usual spirited style, 'are at war with one another. The first which establish themselves by chance in a particular spot tend, by the mere occupancy of space, to exclude other species—the greater choke the smaller; the longest livers replace those which last for a shorter period; the more prolific gradually make themselves masters of the ground, which species multiplying more slowly would otherwise fill.'

In this continual strife, he observes, it is not always the resources of the plant itself which enable it to maintain or extend its ground. Its success depends, in a great measure, on the number of its foes or allies, among the animals and plants inhabiting the same region. Thus, for example, a herb which loves the shade may multiply, if some tree with spreading boughs and dense foliage flourish in the neighbourhood. Another, which, if unassisted, would be overpowered by the rank growth of some hardy competitor, is secure because its leaves are unpalatable to cattle; which, on the other hand, annually crop down its antagonist, and rarely suffer it to ripen its seed.

Oftentimes we see some herb which has flowered in the midst of a thorny shrub, when all the other individuals of the same species, in the open fields around, are eaten down, and cannot bring their seed to maturity. In this case, the shrub has lent his armour of spines and prickles to protect the defenceless herb against the mouths of the cattle; and thus a few individuals which occupied, perhaps, the most unfavourable station in regard to exposure, soil, and other circumstances, may, nevertheless, by the aid of an ally, become the principal source whereby the winds are supplied with

seeds which perpetuate the species throughout the surrounding tract.* Thus, in the New Forest in Hampshire, the young oaks which are not consumed by the deer, or uprooted by the swine, are often indebted to the holly for their escape.

In the above examples we see one plant shielding another from the attacks of animals; but instances are, perhaps, still more numerous, where some animal defends a plant against the enmity of some other subject of the vegetable kingdom. Scarcely any beast, observes Linnæus, will touch the nettle, but fifty different kinds of insects are fed by it.† Some of these seize upon the root, others upon the stem; some eat the leaves; others devour the seeds and flowers: but for this multitude of enemies, the nettle (*Urtica dioica*) would annihilate a great number of plants. The same naturalist tells us, in his 'Tour in Scania,' that goats were turned into an island which abounded with the *Agrostis arundinacea*, where they perished by famine; but horses which followed them grew fat on the same plant. The goat, also, he says, thrives on the meadow-sweet and water-hemlock, plants which are injurious to cattle.‡

Agency of insects.—Every plant, observes Wilcke, has its proper insect allotted to it to curb its luxuriancy, and to prevent it from multiplying to the exclusion of others. 'Thus grass in meadows sometimes flourishes so as to exclude all other plants: here the *Phalæna graminis* (*Bombyx gram.*), with her numerous progeny, finds a well-spread table; they multiply in immense numbers, and the farmer, for some years, laments the failure of his crop; but, the grass being consumed, the moths die with hunger, or remove to another place. Now the quantity of grass being greatly diminished, the other plants, which were before choked by it, spring up, and the ground becomes variegated with a multitude of different species of flowers. Had not Nature given a commission to this minister for that purpose the grass would destroy a great number of species of vegetables, of which the equilibrium is now kept up.'§

* Amœn. Acad. vol. vi. p. 17, § 12.

† Ibid.

‡ Ibid. vol. vii. p. 409.

§ Ibid. vol. vi. p. 17, § 11, 12.

In the above passage allusion is made to the ravages committed in 1740, and the two following years, in many provinces of Sweden, by a most destructive insect. The same moth is said never to touch the foxtail grass, so that it may be classed as a most active ally and benefactor of that species, and as peculiarly instrumental in preserving it in its present abundance.* A discovery of Rolander, cited in the treatise of Wilcke above mentioned, affords a good illustration of the checks and counter-checks which Nature has appointed to preserve the balance of power among species. 'The *Phalæna strobilella* has the fir-cone assigned to it to deposit its eggs upon; the young caterpillars coming out of the shell consume the cone and superfluous seed; but, lest the destruction should be too general, the *Ichneumon strobilellæ* lays its eggs in the caterpillar, inserting its long tail in the openings of the cone till it touches the included insect, for its body is too large to enter. Thus it fixes its minute egg upon the caterpillar, which being hatched, destroys it.'†

Entomologists enumerate many parallel cases where insects, appropriated to certain plants, are kept down by other insects, and these again by parasites expressly appointed to prey on them.‡ Few, perhaps, are in the habit of duly appreciating the extent to which insects are active in preserving the balance of species among plants, and thus regulating indirectly the relative numbers of many of the higher orders of terrestrial animals. The peculiarity of their agency consists in their power of suddenly multiplying their numbers to a degree which could only be accomplished in a considerable lapse of time in any of the larger animals, and then as instantaneously relapsing, without the intervention of any violent disturbing cause, into their former insignificance.

If, for the sake of employing, on different but rare occasions, a power of many hundred horses, we were under the necessity of feeding all these animals at great cost in the intervals when their services were not required, we should greatly admire the invention of a machine, such as the steam-engine, which was capable at any moment of exerting the same

* Kirby and Spence, vol. i. p. 178.

† Amœn. Acad. vol. vi. p. 26, § 14.

‡ Kirby and Spence, vol. iv. p. 218.

degree of strength without any consumption of food during periods of inaction. The same kind of admiration is strongly excited when we contemplate the powers of insect life, in the creation of which the Author of Nature has been so prodigal. A scanty number of minute individuals, to be detected only by careful research, are ready in a few days, weeks, or months, to give birth to myriads, which may repress any degree of monopoly in another species, or remove nuisances, such as dead carcasses, which might taint the air. But no sooner has the destroying commission been executed than the gigantic power becomes dormant—each of the mighty host soon reaches the term of its transient existence, and the season arrives when the whole species passes naturally into the egg, and thence into the larva and pupa state. In this defenceless condition it may be destroyed either by the elements, or by the augmentation of some of its numerous foes which may prey upon it in the early stages of its transformation; or it often happens that in the following year the season proves unfavourable to the hatching of the eggs or the development of the pupæ.

Thus the swarming myriads depart which may have covered the vegetation like the aphides, or darkened the air like locusts. In almost every season there are some species which in this manner put forth their strength, and then, like Milton's spirits, which thronged the spacious hall, 'reduce to smallest forms their shapes immense'—

> ————So thick the aëry crowd
> Swarm'd and were straiten'd; till, the signal given,
> Behold a wonder! they but now who seemed
> In bigness to surpass earth's giant sons,
> Now less than smallest dwarfs.

A few examples will illustrate the mode in which this force operates. It is well known that, among the countless species of the insect creation, some feed on animal, others on vegetable matter; and, upon considering a catalogue of 8,000 British Insects and Arachnidæ, Mr. Kirby found that these two divisions were nearly a counterpoise to each other, the carnivorous being somewhat preponderant. There are also distinct species, some which consume living, others

dead or putrid animal and vegetable substances. One female, of *Musca carnaria*, will give birth to 20,000 young; and the larvæ of many flesh-flies devour so much food in twenty-four hours, and grow so quickly, as to increase their weight two hundred-fold! In five days after being hatched they arrive at their full growth and size, so that there was ground, says Kirby, for the assertion of Linnæus, that three flies of *M. vomitoria* could devour a dead horse as quickly as a lion;* and another Swedish naturalist remarks, that so great are the powers of propagation of a single species even of the smallest insects, that each can commit, when required, more ravages than the elephant.†

Next to locusts, the aphides, perhaps, exert the greatest power over the vegetable world, and, like them, are sometimes so numerous as to darken the air. The multiplication of these little creatures is without parallel, and almost every plant has its peculiar species. Réaumur has proved that in five generations one aphis may be the progenitor of 5,904,900,000 descendants; and it is supposed that in one year there may be twenty generations.‡ Mr. Curtis observes that, as among caterpillars we find some that are constantly and unalterably attached to one or more particular species of plants, and others that feed indiscriminately on most sorts of herbage, so it is precisely with the aphides: some are particular, others more general feeders; and as they resemble other insects in this respect, so they do also in being more abundant in some years than in others.§ In 1793 they were the chief, and in 1798 the sole, cause of the failure of the hops. In 1794, a season almost unparalleled for drought, the hop was perfectly free from them; while peas and beans, especially the former, suffered very much from their depredations.

The ravages of the caterpillars of some of our smaller moths afford a good illustration of the temporary increase of a species. The oak trees of a considerable wood have been stripped of their leaves as bare as in winter, by the caterpillars of a small green moth (*Tortrix viridana*), which has been observed the year following not to abound. The silver Y moth

* Kirby and Spence, vol. i. p. 250.

† Wilcke, Amœn. Acad. c. ii.

‡ Kirby and Spence, vol. i. p. 174.

§ Trans. Linn. Soc. vol. vi.

(*Plusia gamma*), although one of our common species, is not dreaded by us for its devastations; but legions of their caterpillars have at times created alarm in France, as in 1735. Réaumur observes that the female moth lays about 400 eggs; so that if twenty caterpillars were distributed in a garden, and all lived through the winter and became moths in the succeeding May, the eggs laid by these, if half of them were female and all fertile, would in the next generation produce 800,000 caterpillars.* A modern writer, therefore, justly observes that, did not Providence put causes in operation to keep them in due bounds, the caterpillars of this moth alone, leaving out of consideration the 2,000 other British species, might soon destroy more than half of our vegetation.

In the latter part of the last century an ant most destructive to the sugar-cane (*Formica saccharivora*), appeared in such infinite hosts in the island of Grenada, as to put a stop to the cultivation of that vegetable. Their numbers were incredible. The plantations and roads were filled with them; many domestic quadrupeds, together with rats, mice, and reptiles, and even birds, perished in consequence of this plague. It was not till 1780 that they were at length annihilated by torrents of rain, which accompanied a dreadful hurricane.†

Devastations caused by locusts.—We may conclude by mentioning some instances of the devastations of locusts in various countries. Among other parts of Africa, Cyrenaica has been at different periods infested by myriads of these creatures, which have consumed nearly every green thing. The effect of the havoc committed by them may be estimated by the famine they occasioned. St. Augustine mentions a plague of this kind in Africa which destroyed no less than 800,000 men in the kingdom of Massinissa alone, and many more upon the territories bordering upon the sea. It is also related, that in the year 591, an infinite army of locusts migrated from Africa into Italy; and, after grievously ravaging the country, were cast into the sea, when there arose a pestilence from their stench which carried off nearly a million of men and beasts.

* Réaumur, vol. ii. p. 337.

† Kirby and Spence, vol. i. p. 183. Castle, Phil. Trans. xxx. 346.

In the Venetian territory, also, in 1478, more than 30,000 persons are said to have perished in a famine occasioned by this scourge; and other instances are recorded of their devastations in France, Spain, Italy, Germany, &c. In different parts of Russia also, Hungary, and Poland, in Arabia and India, and other countries, their visitations have been periodically experienced. Although they have a preference for certain plants, yet, when these are consumed, they will attack almost all the remainder. In the accounts of the invasions of locusts, the statements which appear most marvellous relate to the prodigious mass of matter which encumbers the sea wherever they are blown into it, and the pestilence arising from its putrefaction. Their dead bodies are said to have been, in some places, heaped one upon another, to the depth of four feet, in Russia, Poland, and Lithuania; and when, in Southern Africa, they were driven into the sea, by a north-west wind, they formed, says Barrow, along the shore, for fifty miles, a bank three or four feet high.* But when we consider that forests are stripped of their foliage, and the earth of its green garment, for thousands of square miles, it may well be supposed that the volume of animal matter produced may equal that of great herds of quadrupeds and flights of large birds suddenly precipitated into the sea.

The occurrence of such events at certain intervals, in hot countries, like the severe winters and damp summers returning after a series of years in the temperate zone, may affect the proportional numbers of almost all classes of animals and plants, and probably prove fatal to the existence of many which would otherwise thrive there; while, on the contrary, the same occurrences can scarcely fail to be favourable to certain species which, if deprived of such aid, might not maintain their ground.

Although it may usually be remarked that the extraordinary increase of some one species is immediately followed and checked by the multiplication of another, yet this does not always happen; partly because many species feed in common on the same kinds of food, and partly because many kinds of

* Travels in Africa, p. 257. Kirby and Spence, vol. i. p. 215.

food are often consumed indifferently by one and the same species. In the former case, where a variety of different animals have precisely the same taste, as, for example, when many insectivorous birds and reptiles devour alike some particular fly or beetle, the unusual numbers of these insects may cause only a slight and almost imperceptible augmentation of each of these species of bird and reptile. In the other instance, where one animal preys on others of almost every class, as, for example, where some of our English hawks or buzzards (*Buteo*) devour not only small quadrupeds, as rabbits and field-mice, but also birds, frogs, lizards, and insects, the profusion of any one of these last may cause all such general feeders to subsist more exclusively upon the species thus in excess, by which means the balance may be restored.

Agency of omnivorous animals.—The number of species which are nearly omnivorous is considerable; and although every animal has, perhaps, a predilection for some one description of food rather than another, yet some are not even confined to one of the great kingdoms of the organic world. Thus, when the racoon of the West Indies can procure neither fowls, fish, snails, nor insects, it will attack the sugar canes, and devour various kinds of grain. The civets, when animal food is scarce, maintain themselves on fruits and roots. Numerous birds, which feed indiscriminately on insects and plants, are perhaps more instrumental than any other of the terrestrial tribes in preserving a constant equilibrium between the relative numbers of different classes of animals and vegetables. If the insects become very numerous and devour the plants, these birds will immediately derive a larger portion of their subsistence from insects, just as the Arabians, Syrians, and Hottentots feed on locusts, when the locusts devour their crops.

Reciprocal influence of aquatic and terrestrial species.—The intimate relation of the inhabitants of the water to those of the land, and the influence exerted by each on the relative number of species, must not be overlooked amongst the complicated causes which determine the existence of animals and plants in certain regions. A large portion of the amphibious

quadrupeds and reptiles prey partly on aquatic plants and animals, and in part on terrestrial; and a deficiency of one kind of prey causes them to have immediate recourse to the other. The voracity of certain insects, as the dragon-fly, for example, is confined to the water during one stage of their transformations, and in their perfect state to the air. Innumerable water-birds, both of rivers and seas, derive in like manner their food indifferently from either element; so that the abundance or scarcity of prey in one induces them either to forsake or more constantly to haunt the other. Thus an intimate connection between the state of the animate creation in a lake or river, and in the adjoining dry land, is maintained; or between a continent, with its lakes and rivers, and the ocean. It is well known that many birds migrate, during stormy seasons, from the sea-shore into the interior, in search of food; while others, on the contrary, urged by like wants, forsake their inland haunts, and live on substances rejected by the tide.

The migration of fish into rivers during the spawning season supplies another link of the same kind. Suppose the salmon to be reduced in numbers by some marine foes, as by seals and grampuses, the consequence must often be, that in the course of a few years the otters at the distance of several hundred miles inland, will be lessened in number from the scarcity of fish. On the other hand, if there be a dearth of food for the young fry of the salmon in rivers and estuaries, so that few return to the sea, the sand-eels and other marine species, which are usually kept down by the salmon, will swarm in greater profusion.

It is unnecessary to accumulate more illustrations in order to prove that the stations of different plants and animals depend on a great complication of circumstances,—on an immense variety of relations in the state of the animate and inanimate worlds. Every plant requires a certain climate, soil, and other conditions, and often the aid of many animals, in order to maintain its ground. Many animals feed on certain plants, being often restricted to a small number, and sometimes to one only; other members of the animal kingdom feed on plant-eating species, and thus become dependent on

the conditions of the *stations*, not only of their prey, but of the plants consumed by them.

How changes in physical geography affect the distribution of species.—Thus by means of numerous checks and counter-checks the state of the animal and vegetable kingdoms continues from century to century, and even perhaps for tens of thousands of years, the same, except where man interferes; but independently of human intervention, neither the zoological nor botanical provinces can remain for indefinite periods unaltered.

Nature is continually engaged in the task of sowing seeds and colonising animals; were this not the case the depopulation of a certain portion of the habitable sea and land would, even in a few years, be considerable, so great is the instability of the earth's surface. Whenever a river transports sediment into a lake or sea, so as materially to diminish its depth, the aquatic animals and plants which delight in deep water are expelled: the tract, however, is not allowed to remain useless; but is soon peopled by species which require more light and heat, and thrive where the water is shallow. Every addition made to the land by the encroachment of the delta of a river banishes many aquatic species from their native abodes; but the new-formed plain is not permitted to lie unoccupied, being instantly covered with terrestrial vegetation. The ocean devours continuous lines of sea-coasts, and precipitates forests or rich pasture land into the waves; but this space is not lost to the animate creation; for shells and sea-weeds soon adhere to the new-made cliffs, and numerous fish people the channel which the current has scooped out for itself. No sooner has a volcanic island been thrown up than some lichens begin to grow upon it, and it is sometimes clothed with verdure while smoke and ashes are still occasionally thrown from the crater. The cocoa, pandanus, and mangrove take root upon the coral reef before it has fairly risen above the waves. The burning stream of lava that descends from Etna rolls through the stately forest, and converts to ashes every tree and herb which stands in its way; but the black strip of land thus desolated is covered again, in the course of time, with oaks,

pines, and chestnuts, as luxuriant as those which the fiery torrent swept away.

Every flood and landslip, every wave which a hurricane or earthquake throws upon the shore, every stream of lava or shower of volcanic dust and ashes which buries a country far and wide to the depth of many feet, every advance of the sand-flood, every conversion of salt water into fresh, when rivers alter their main channel of discharge, every permanent variation in the rise or fall of tides in an estuary—these and countless other causes displace, in the course of a few centuries, certain plants and animals from stations which they previously occupied. If, therefore, the Author of Nature had not been prodigal of those numerous contrivances, before alluded to, for spreading all classes of organic beings over the earth—if He had not ordained that the fluctuations of the animate and inanimate creation should be in perfect harmony with each other, it is evident that considerable spaces, now the most habitable on the globe, would soon be as devoid of life as are the Alpine snows, or the moving sands and salt plains of the Sahara.

The powers, then, of migration and diffusion, conferred, as already shown, on animals and plants, are indispensable to enable them to maintain their ground, and would be necessary, even though it were never intended that a species should gradually extend its geographical range. But a facility of shifting their quarters being once given, it cannot fail to happen that the inhabitants of one province should occasionally penetrate into some other; since the strongest of those barriers which I before described as separating distinct regions are all liable to be thrown down, one after the other, during the vicissitudes of the earth's surface.

We have seen in the Twelfth Chapter* how vast a succession of changes in the physical geography of the globe has been revealed to us by geology. Although these changes are incessant, they proceed at so slow a rate that mankind at large are wholly unconscious of their reality. It would not be easy for the naturalist to take account of the advantage which one

* Vol. I. p. 252.

species may gain over another in the course of a few centuries, even at those points on the borders of two distinct provinces where the struggle for existence is most keen. At such points the rate of change must far outstrip the average pace at which it proceeds in the organic world generally. If the ocean should gradually wear its way through an isthmus, like that of Suez, it would open a passage for the intermixture of the aquatic tribes of two seas (the Mediterranean and Red Sea) previously disjoined, and would, at the same time, close a free communication which the terrestrial plants and animals of two continents had before enjoyed. These would be, perhaps, the most important consequences, in regard to the distribution of species, which would result from the breach made by the sea in such a spot; but there would be others of a distinct nature, such as the conversion of a certain tract of land, which formed the isthmus, into the sea. This space, previously occupied by terrestrial plants and animals, would be immediately delivered over to the aquatic; a local revolution which might have happened in innumerable other parts of the globe, without being attended by any alteration in the blending together of the species of two distinct provinces.

So if the narrow isthmus of Panama were to sink down gradually, a communication would at length be established between two seas which are now inhabited by fish, mollusks, crustaceans, and other aquatic tribes nearly all of them specifically distinct. A contest would take place between thousands of allied species which in the course of time would give rise to the predominance of some and the decline or total extinction of others. If Spain were joined to Morocco, by the upheaval and laying dry of the submarine ridge 1,000 feet deep, before described,* the Mediterranean fauna would be separated from that of the Atlantic, and there would be a fusion of the terrestrial plants of Northern Africa with those of Southern Europe. Or we may imagine a land communication to be caused by volcanic outbursts in the straits of Lombok,† uniting the islands of Bali and Lombok. This would bring

* See above, Vol. I. p. 496. † See Map, fig. 138, p. 350.

about a conflict between the land-birds, insects, and plants of the Indian and Australian provinces, which could not fail to add to the numerical predominance of some species at the expense of others, while some might be exterminated. But even such fluctuations would to a human observer appear slow in the extreme, because a communication formed by a new volcanic island will not simply take thousands of years, but perhaps thousands of centuries, for its accomplishment, and few of the species capable of profiting by the removal of the old barrier would wait till the two islands were completely joined.

Extension of the range of one species alters that of others.—In reference to the extinction of species it is important to bear in mind, that when any region is stocked with as great a variety of animals and plants as its productive powers will enable it to support, the addition of any new species to the *permanent* numerical increase of one previously established, must always be attended either by the local extermination or the numerical decrease of some other species.

There may undoubtedly be considerable fluctuations from year to year, and the equilibrium may be again restored without any permanent alteration; for, in particular seasons, a greater supply of heat, humidity, or other causes, may augment the total quantity of vegetable produce, in which case all the animals subsisting on vegetable food, and others which prey on them, may multiply without any one species giving way: but whilst the aggregate quantity of vegetable produce remains unaltered, the progressive increase of one animal or plant implies the decline of another.

All agriculturists and gardeners are familiar with the fact that when weeds intrude themselves into the space appropriated to cultivated species, the latter are starved in their growth or stifled. If we abandon for a short time a field or garden, a host of indigenous plants,

> The darnel, hemlock, and rank fumitory,

pour in and obtain the mastery, extirpating the exotics, or putting an end to the monopoly of some native plants.

If we enclose a park, and stock it with as many deer as the

herbage will support, we cannot add sheep without lessening the number of the deer; nor can other herbivorous species be subsequently introduced, unless the individuals of each species in the park become fewer in proportion.

So, if there be an island where leopards are the only beasts of prey, and the lion, tiger, and hyæna afterwards enter, the leopards, if they stand their ground, will be reduced in number. If the locusts then arrive and swarm greatly, they may deprive a large number of plant-eating animals of their food, and thereby cause a famine, not only among them, but among the beasts of prey: certain species, perhaps, which had the weakest footing in the island may thus be annihilated. Although our knowledge of the history of the animate creation dates from so recent a period, that we can scarcely trace the advance or decline of any animal or plant, except in those cases where the influence of man has intervened; yet we can easily conceive what must happen when some new colony of wild animals or plants enters a region for the first time, and succeeds in establishing itself.

Supposed effects of the first entrance of the polar bear into Iceland.—Let us consider how great are the devastations committed at certain periods by the Greenland bears, when they are drifted to the shores of Iceland in considerable numbers on the ice. These periodical invasions are formidable even to man; so that when the bears arrive, the inhabitants collect together, and go in pursuit of them with fire-arms—each native who slays one being rewarded by the king of Denmark. The Danes of old, when they landed in their marauding expeditions upon our coast, hardly excited more alarm, nor did our islanders muster more promptly for the defence of their lives and property against the common enemy, than the modern Icelanders against these formidable brutes. It often happens, says Henderson, that the natives are pursued by the bear when he has been long at sea, and when his natural ferocity has been heightened by the keenness of hunger; if unarmed, it is frequently by stratagem only that they make their escape.*

* Journal of a Residence in Iceland, p. 27.

Let us cast our thoughts back to the period when the first polar bears reached Iceland, before it was colonised by the Norwegians in 874; we may imagine the breaking up of an immense barrier of ice like that which, in 1816 and the following year, disappeared from the east coast of Greenland, which it had surrounded for four centuries. By the aid of such means of transportation a great number of these quadrupeds might effect a landing at the same time, and the havoc which they would make among the species previously settled in the island would be terrific. The deer, foxes, seals, and even birds, on which these animals sometimes prey, would be soon thinned down.

But this would be a part only, and probably an insignificant portion, of the aggregate amount of change brought about by the new invader. The plants on which the deer fed, being less consumed in consequence of the lessened numbers of that herbivorous species, would soon supply more food to several insects, and probably to some terrestrial testacea, so that the latter would gain ground. The increase of these would furnish other insects and birds with food, so that the numbers of these last would be augmented. The diminution of the seals would afford a respite to some fish which they had persecuted; and these fish, in their turn, would then multiply and press upon their peculiar prey. Many water-fowls, the eggs and young of which are devoured by foxes, would increase when the foxes were thinned down by the bears; and the fish on which the water-fowls subsisted would then, in their turn, be less numerous. Thus the numerical proportions of a great number of the inhabitants, both of the land and sea, might be permanently altered by the settling of one new species in the region; and the changes caused indirectly would ramify through all classes of the living creation, and be almost endless.

An actual illustration of what we have here only proposed hypothetically, is in some degree afforded by the selection of small islands by the eider duck for its residence during the season of incubation, its nests being seldom if ever found on the shores of the mainland, or even of a large island. The Icelanders are so well aware of this, that they have expended

a great deal of labour in forming artificial islands, by separating from the mainland certain promontories, joined to it by narrow isthmuses. This insular position is necessary to guard against the destruction of the eggs and young birds, by foxes, dogs, and other animals. One year, says Sir W. Hooker, it happened that, in the small island of Vidoe, adjoining the coast of Iceland, a fox got over *upon the ice*, and caused great alarm, as an immense number of ducks were then sitting on their eggs or young ones. It was long before he was taken, which was at last, however, effected by bringing another fox to the island, and fastening it by a string near the haunt of the former, by which he was allured within shot of the hunter.*

Increase of reindeer imported into Iceland.—As an example of the rapidity with which a large tract may become peopled by the offspring of a single pair of quadrupeds, it may be mentioned that in the year 1773 thirteen reindeer were exported from Norway, only three of which reached Iceland. These were turned loose into the mountains of Guldbringè Syssel, where they multiplied so greatly, in the course of forty years, that it was not uncommon to meet with herds, consisting of from forty to one hundred, in various districts.

The reindeer, observes a modern writer, is in Lapland a loser by his connection with man, but Iceland will be this creature's paradise. There is, in the interior, a tract which Sir G. Mackenzie computes at not less than 40,000 square miles, without a single human habitation, and almost entirely unknown to the natives themselves. There are no wolves; the Icelanders will keep out the bears; and the reindeer, being almost unmolested by man, will have no enemy whatever, unless it has brought with it its own tormenting gad-fly.†

Ulloa in his voyage, and Buffon on the authority of old writers, relate a fact which illustrates very clearly the principle before explained, of the check which the increase of one animal necessarily offers to that of another. The Spaniards

* Tour in Iceland, vol. i. p. 64, 2nd edit. † Travels in Iceland in 1810, p. 342.

had introduced goats into the island of Juan Fernandez, where they became so prolific as to furnish the pirates, who infested those seas, with provisions. In order to cut off this resource from the buccaneers, a number of dogs were turned loose into the island; and so numerous did they become in their turn, that they destroyed the goats in every accessible part, after which the number of the wild dogs again decreased.*

It is usually the first appearance of an animal or plant, in a region to which it was previously a stranger, that gives rise to the chief alteration; since, after a time, an equilibrium is again established. But it must require ages before such a new adjustment of the relative forces of so many conflicting agents can be definitely settled. The causes in simultaneous action are so numerous, that they admit of an almost infinite number of combinations; and it is necessary that all these should have occurred once before the total amount of change, capable of flowing from any new disturbing force, can be estimated.

Thus, for example, suppose that once in two centuries a frost of unusual intensity, or a volcanic eruption of great violence accompanied by floods from the melting of glaciers, should occur in Iceland; or an epidemic disease, fatal to the larger number of individuals of some one species, and not affecting others,—these, and a variety of other contingencies, all of which may occur at once, or at periods separated by different intervals of time, ought to happen before it would be possible for us to declare what ultimate alteration the presence of any new comers, such as the bear or reindeer before mentioned, might occasion in the animal population of the isle.

Every new condition in the state of the organic or inorganic creation, a new animal or plant, an additional snow-clad mountain, any permanent change, however slight in comparison to the whole, gives rise to a new order of things, and may make a material change in regard to some one or more species. Yet a swarm of locusts, or a frost of extreme intensity, or an epidemic disease, may pass away without any

* Buffon, vol. v. p. 100. Ulloa's Voyage, vol. ii. p. 220.

great apparent derangement; no species may be lost, and all may soon recover their former relative numbers, because the same scourges may have visited the region again and again, at preceding periods. Every plant that was incapable of resisting such a degree of cold, every animal which was exposed to be entirely cut off by an epidemic or by famine caused by the consumption of vegetation by the locusts, may have perished already, so that the subsequent recurrence of similar catastrophes is attended only by a temporary change.

Extirpation of species by man.—That man is, geologically speaking, of very modern origin we may assume, although we have recently obtained satisfactory proofs that he was contemporary with the mammoth and many other extinct mammalia, and that he has survived considerable changes in the physical geography of the globe.

The number of human beings now peopling the earth is generally supposed to amount to eight hundred millions, so that we may easily understand how great a number of beasts of prey, birds, and animals of every class, this prodigious population must have displaced, independently of the still more important consequences which have followed from the derangement brought about by man in the relative numerical strength of particular species.

It may perhaps be said, that man has, in no small degree, compensated for the appropriation to himself of the food of many animals by artificially improving the natural productiveness of soils, by irrigation, manure, and a judicious intermixture of mineral ingredients conveyed from different localities. But it admits of reasonable doubt whether, upon the whole, we fertilise or impoverish the lands which we occupy. This assertion may seem startling to many; because they are so much in the habit of regarding the sterility or productiveness of land in relation to the wants of man, and not as regards the organic world generally. It is difficult, at first, to conceive, if a morass be converted into arable land, and made to yield a crop of grain, even of moderate abundance, that we have not improved the capabilities of the habitable surface—that we have not empowered it to support

a larger quantity of organic life. In such cases, however, a tract, before of no utility to man, may be reclaimed, and become of high agricultural importance, though it may, nevertheless, yield a scantier vegetation. If a lake be drained, and turned into a meadow, the space will provide sustenance for man, and many terrestrial animals serviceable to him, but not, perhaps, so much food as it previously yielded to the aquatic races.

The felling of dense and lofty forests, which covered, even within the records of history, a considerable space on the globe, now tenanted by civilised man, must generally have lessened the amount of vegetable food throughout the space where these woods grew. We must also take into our account the area covered by towns, and a still larger surface occupied by roads.

If we force the soil to bear extraordinary crops one year, we are, perhaps, compelled to let it lie fallow the next. But nothing so much counterbalances the fertilising effects of human art as the extensive cultivation of foreign herbs and shrubs, which, although they are often more nutritious to man, seldom thrive with the same rank luxuriance as the native plants of a district. Man is, in truth, continually striving to diminish the natural diversity of the *stations* of animals and plants in every country, and to reduce them all to a small number fitted for species of economical use. He may succeed perfectly in attaining his object, even though the vegetation be comparatively meagre, and the total amount of animal life be greatly lessened.

When St. Helena was discovered about the year 1506, it was entirely covered with forests, the trees drooping over the tremendous precipices that overhang the sea. Now, says Dr. Hooker, all is changed; fully five-sixths of the island are entirely barren, and by far the greater part of the vegetation which exists, whether herbs, shrubs, or trees, consists of introduced European, American, African, and Australian plants, which propagated themselves with such rapidity that the native plants could not compete with them. These exotic species, together with the goats, which being carried to the island destroyed the forests by devouring all

the young plants, are supposed to have utterly annihilated about 100 peculiar and indigenous species, all record of which is lost to science, except those of which specimens were collected by the late Dr. Burchell and are now in the herbarium of Kew.*

In the district of Canterbury, New Zealand, Mr. Locke Travers, writing in 1863, says that the spread of European and other foreign plants is surprisingly rapid. The cow-grass (*Polygonum aviculare*), the common dock, and the sow thistle grow luxuriantly, the water-cress increases in the still rivers so as to threaten to choke them up altogether, and to put the colonists to the expense of £300 annually in keeping open a single stream, the Avon, which runs through Christchurch. Stems of this water-cress have been measured 12 feet long and three-quarters of an inch in diameter. In some mountain districts the white clover is displacing the native grasses, and foreign trees, such as poplars, and willows, and the gum-trees of Australia, are growing rapidly. In fact, the young native vegetation appears to shrink from competition with these more vigorous intruders.†

Spix and Martius have given a lively description of the incredible number of insects which lay waste the crops in Brazil, besides swarms of monkeys, flocks of parrots, and other birds, as well as the paca, agouti, and wild swine. They describe the torment which the planter and the naturalist suffer from the musquitoes, and the devastation of the ants and blattæ; they speak of the dangers to which they were exposed from the jaguar, the poisonous serpents, crocodiles, scorpions, centipedes, and spiders. But with the increasing population and cultivation of the country, say these naturalists, these evils will gradually diminish; when the inhabitants have cut down the woods, drained the marshes, made roads in all directions, and founded villages and towns, man will, by degrees, triumph over the rank vegetation and the noxious animals, and all the elements will second and amply recompense his activity.‡

* Hooker, Insular Floras, Brit. Assoc. Nottingham, 1866. Gardener's Chronicle, 1867.

† Locke Travers, cited by Hooker, Nat. Hist. Rev. 1864, p. 124.

‡ Travels in Brazil, vol. i. p. 260.

Indigenous quadrupeds and birds extirpated in Great Britain.—Let us make some enquiries into the extent of the influence which the progress of society has exerted during the last seven or eight centuries, in altering the distribution of indigenous British animals. Dr. Fleming, in an able memoir on the subject, has enumerated the best authenticated examples of the decrease or extirpation of certain species during a period when our population has made the most rapid advances. I shall offer a brief outline of his results.*

The stag, as well as the fallow deer and the roe, were formerly so abundant in our island, that, according to Lesley, from five hundred to a thousand were slain at a hunting-match; but the native races would already have been extinguished, had they not been carefully preserved in certain forests. The otter, the marten, and the polecat were also in sufficient numbers to be pursued for the sake of their fur; but they have now been reduced within very narrow bounds. The wild cat and fox have also been sacrificed throughout the greater part of the country, for the security of the poultry-yard or the fold. Badgers have been expelled from nearly every district, which at former periods they inhabited.

Besides these, which have been driven out from their favourite haunts, and everywhere reduced in number, there are some which have been wholly extirpated; such as the ancient breed of indigenous horses, and the wild boar; of the wild oxen a few remains are still preserved in some of the old English parks. The beaver, which is eagerly sought after for its fur, had become scarce at the close of the ninth century; and, by the twelfth century, was only to be met with, according to Giraldus de Barri, in one river in Wales, and another in Scotland. The wolf, once so much dreaded by our ancestors, is said to have maintained its ground in Ireland so late as the beginning of the eighteenth century (1710), though it had been extirpated in Scotland thirty years before, and in England at a much earlier period. The bear, which, in Wales, was regarded as a beast of chase equal to

* Ed. Phil. Journ., No. xxii. p. 287. Oct. 1824.

the hare or the boar, only perished, as a native of Scotland, in the year 1057.*

Many native birds of prey have also been the subjects of unremitting persecution. The eagles, larger hawks, and ravens, have disappeared from the more cultivated districts. The haunts of the mallard, the snipe, the redshank, and the bittern, have been drained equally with the summer dwellings of the lapwing and the curlew. But these species still linger in some portion of the British Isles; whereas the larger capercailzies, formerly natives of the pine-forests of Ireland and Scotland, had been quite destroyed towards the close of the last century, but were successfully reintroduced into Perthshire about the year 1824. The egret and the crane, which appear to have been formerly very common in Scotland, are now only occasional visitants.†

The bustard (*Otis tarda*), observes Graves, in his British Ornithology,‡ 'was formerly seen on the downs and heaths of various parts of our island, in flocks of forty or fifty birds; whereas it is now (1821) a circumstance of rare occurrence to meet with a single individual.' Bewick also remarks, 'that they were formerly more common in this island than at present; they are now found only in the open counties of the south and east—in the plains of Wiltshire, Dorsetshire, and some parts of Yorkshire.'§ In the few years that have elapsed since Bewick wrote, this bird has entirely disappeared from the British Isles. These changes, it may be observed, are derived from very imperfect memorials, and relate only to the larger and more conspicuous animals inhabiting a small spot on the globe; but they cannot fail to exalt our conception of the enormous revolutions which, in the course of thousands of years, the whole human species must have effected.

Extinction of the dodo.—The kangaroo and the emu are retreating rapidly before the progress of colonisation in Australia; and it scarcely admits of doubt, that the general cultivation of that country must lead to the extirpation of both. The most striking example of the loss, even within the last

* Fleming, Ed. Phil. Journ. No. xxii. p. 295.

† Fleming, ibid., p. 292.

‡ Vol. iii. London, 1821.

§ Land Birds, vol. i., p. 316, ed. 1821.

two centuries, of a remarkable species, is that of the dodo—a bird first seen by the Dutch, when they landed on the Isle of France, at that time uninhabited, immediately after the discovery of the passage to the East Indies by the Cape of Good Hope. It was of a large size, and singular form; its wings short, like those of an ostrich, and wholly incapable of sustaining its heavy body, even for a short flight. In its general appearance it differed from the ostrich, cassowary, or any known bird.*

Many naturalists gave figures of the dodo after the commencement of the seventeenth century; and there is a painting of it in the British Museum, which is said to have been taken from a living individual. Beneath the painting is a leg, in a fine state of preservation, which ornithologists are agreed cannot belong to any other known bird. In the museum at Oxford, also, there is a foot and a head in an imperfect state.

In spite of the most active search, during the last century, no information respecting the dodo was obtained, and some authors went so far as to pretend that it had never existed; but a great mass of satisfactory evidence in favour of its recent existence has now been collected by Mr. Broderip,† and by Mr. Strickland and Dr. Melville. Mr. Strickland, agreeing with Professor Reinhardt, of Copenhagen, in referring the dodo to the Columbidæ, called it a 'vulture-like frugivorous pigeon.' It appears, also, that another short-winged bird of the same order, called 'The Solitaire,' inhabited the island of Rodrigues, 300 miles east of the Mauritius, and has been exterminated by man, as have one or two different but allied birds of the Isle of Bourbon.‡ In

* Some have complained that inscriptions on tomb-stones convey no general information, except that individuals were born and died, accidents which must happen alike to all men. But the death of a *species* is so remarkable an event in natural history that it deserves commemoration, and it is with no small interest that we learn, from the archives of the University of Oxford, the exact day and year when the remains of the last specimen of the dodo, which had been permitted to rot in the Ashmolean Museum, were cast away. The relics, we are told, were 'a musæo subducta, annuente vice-cancellario aliisque curatoribus, ad ea lustranda convocatis, die Januarii 8vo, A.D. 1755.' Zool. Journ. No. 12, p. 559. 1828.

† Penny Cyclopædia, 'Dodo,' 1837.

‡ Messrs. Strickland and Melville on 'the Dodo and its Kindred.' London, 1848.

the year 1865 parts of the skeleton of a dodo were dug up in a bog near the sea in the island of Mauritius. They were sent to Professor Owen, and were described by him in the Transactions of the Zoological Society for 1867.* Speaking of the extinct bird as the great 'ground-dove' of the Mauritius, he speculates on this peculiar species having originated in that uninhabited and thickly wooded island, where there was no animal powerful enough to contend with it, and from which it would be required to escape by flight. He therefore conceives that, 'finding food enough scattered over the ground, it ceased to exert its wings in raising the heavy trunk, and so gradually gained bulk in the course of many generations. Hence the organs of flight would, according to Lamarckian principles, be atrophied by disease and diminished in size and strength, while the hind limbs, having an increasing weight to support and being exercised by habitual motion on the land, would acquire larger dimensions.' †

Rapid propagation of domestic quadrupeds over the American continent.—The agency of man in multiplying the numbers of large herbivorous quadrupeds of domesticated races may be regarded as one of the most obvious causes of the extermination of species. On this, and on several other grounds, the introduction of the horse, ox, and other mammalia, into America, and their rapid propagation over that continent within the last three centuries, is a fact of great importance in natural history. The extraordinary herds of wild cattle and horses which overran the plains of South America sprang from a very few pairs first carried over by the Spaniards; and they prove that the wide geographical range of large species in great continents does not necessarily imply that they have existed there from remote periods.

Humboldt observes, in his Travels, on the authority of Azara, that it is believed that there exist, in the Pampas of Buenos Ayres, twelve million cows and three million horses,

* Since this date more remains have been discovered from which an almost perfect skeleton has been constructed at the British Museum, descriptions and figures of which were published by Prof. Owen in 1871. Trans. of the Zool. Soc. vol. vii. p. 513.

† Zool. Soc. Trans. 1867.

without comprising in this enumeration the cattle that have no acknowledged proprietor. In the Llanos of Caraccas, the rich hateros, or proprietors of pastoral farms, are entirely ignorant of the number of cattle they possess. The young are branded with a mark peculiar to each herd, and some of the most wealthy owners mark as many as 14,000 a year.* In the northern plains, from the Orinoco to the lake of Maracaybo, M. Depons reckoned that 1,200,000 oxen, 180,000 horses, and 90,000 mules, wandered at large.† In some parts of the valley of the Mississippi, especially in the country of the Osage Indians, wild horses were immensely numerous in the early part of this century.

The establishment of black cattle in America dates from Columbus's second voyage to St. Domingo. They there multiplied rapidly; and that island presently became a kind of nursery from which these animals were successively transported to various parts of the continental coast, and from thence into the interior. Notwithstanding these numerous exportations, in twenty-seven years after the discovery of the islands, herds of 4,000 head, as we learn from Oviedo, were not uncommon, and there were even some that amounted to 8,000. In 1587, the number of hides exported from St. Domingo alone, according to Acosta's report, was 35,444; and in the same year there were exported 64,350, from the ports of New Spain. This was in the sixty-fifth year after the taking of Mexico, previous to which event the Spaniards, who came into that country, had not been able to engage in anything else than war.‡ Everyone is aware that these animals are now established throughout the American continent from Canada to the Straits of Magellan.

The ass has thriven very generally in the New World; and we learn from Ulloa, that in Quito they ran wild, and multiplied in amazing numbers, so as to become a nuisance. They grazed together in herds, and when attacked defended themselves with their mouths. If a horse happened to stray into the places where they fed, they all fell upon him, and did not cease biting and kicking till they left him dead.§ This fact

* Pers. Nar. vol. iv.

† Quarterly Review, vol. xxi. p. 335.

‡ Ibid.

§ Ulloa's Voyage. Wood's Zoog. vol. i. p. 9.

illustrates the power of one of those barriers—namely, that of preoccupancy, which we before alluded to (p. 133)—as being often most effective in limiting the range of species.

The first hogs were carried to America by Columbus, and established in the island of St. Domingo the year following its discovery, in November, 1493. In succeeding years they were introduced into other places where the Spaniards settled, and, in the space of half a century, they were found established in the New World, from the latitude of 25° north, to the 40th degree of south latitude. Sheep, also, and goats have multiplied enormously in the New World, as have also the cat and the rat, which last, as before stated, has been imported unintentionally in ships. The dogs introduced by man which have at different periods become wild in America, hunted in packs, like the wolf and the jackal, destroying not only hogs, but the calves and foals of the wild cattle and horses.

Besides the quadrupeds above enumerated, our domestic fowls have also thriven in the West Indies and America, where they have now the common fowl, the goose, the duck, the peacock, the pigeon, and the guinea-fowl. As these were often taken suddenly from the temperate to very hot regions, they were not reared at first without much difficulty; but after a few generations they became habituated to the climate, which, in many cases, approached much nearer than that of Europe to the temperature of their original native countries. The fact of so many millions of wild and tame individuals of our domestic species, almost all of them the largest quadrupeds and birds, having been propagated throughout the new continent within the short period that has elapsed since the discovery of America, while no appreciable improvement can have been made in the productive powers of that vast continent, affords abundant evidence of the extraordinary changes which accompany the diffusion and progressive advancement of the human race over the globe.

Power of exterminating species no prerogative of man.—When we reflect how many millions of square miles of the fertile land, occupied originally by a boundless variety of animal

and vegetable forms, have been already brought under the dominion of man, and compelled, in a great measure, to yield nourishment to him, and to a limited number of plants and animals which he has caused to increase, we must at once be convinced, that the annihilation of a multitude of species has already been effected, and will continue to go on hereafter, in certain regions, in a still more rapid ratio, as the colonies of highly civilised nations spread themselves over unoccupied lands.

Yet, if we wield the sword of extermination as we advance, we have no reason to repine at the havoc committed, nor to fancy, with the Scottish poet, that 'we violate the social union of nature;' or complain, with the melancholy Jaques, that we

> Are mere usurpers, tyrants, and what's worse,
> To fright the animals and to kill them up
> In their assign'd and native dwelling-place.

We have only to reflect, that in thus obtaining possession of the earth by conquest, and defending our acquisitions by force, we exercise no exclusive prerogative. Every species which has spread itself from a small point over a wide area must, in like manner, have marked its progress by the diminution or the entire extirpation of some other, and must maintain its ground by a successful struggle against the encroachments of other plants and animals. That minute parasitic plant, called 'the rust' in wheat, has, like the Hessian fly, the locust, and the aphis, caused famines ere now amongst the 'lords of the creation.' The most insignificant and diminutive species, whether in the animal or vegetable kingdom, have each slaughtered their thousands, as they disseminated themselves over the globe, as well as the lion, when first it spread itself over the tropical regions of Africa.

Concluding remarks on extinction.—From what has now been said of the effect of changes which are always going on in the condition of the habitable surface of the globe, and the manner in which some species are constantly extending their range at the expense of others, it may be deduced, as a corollary, that the species existing at any particular period, may, in the course of ages, become extinct one after the

other. 'They must die out,' to borrow an emphatical expression from Buffon, 'because Time fights against them.'

If such then be a law of the organic world, if every species is continually losing some of its varieties and every genus some of its species, it follows that the transitional links which once, according to the doctrine of Transmutation, must have existed, will, in the great majority of cases, be missing. We learn from geological investigations that throughout an indefinite lapse of ages the whole animate creation has been decimated again and again. Sometimes a single representative alone remains of a type once dominant, or of which the fossil species may be reckoned by hundreds. We rarely find that whole orders have disappeared, yet even this is notably the case in the class of reptiles, which has lost some orders characterised by a higher organisation than any now surviving in that class. Certain genera of plants and animals which seem to have been wholly wanting, and others which were feebly represented, in the Tertiary period, are now rich in species, and appear to be in such perfect harmony with the present conditions of existence, that they present us with countless varieties confounding the zoologist or botanist who undertakes to describe and classify them.

We have only to reflect on the causes of extinction enumerated in this chapter, and we at once foresee the time when even in these genera so many gaps will occur, so many transitional forms will be lost, that there will no longer be any difficulty in assigning definite limits to each surviving species. The blending therefore of one generic or specific form into another, must be an exception to the general rule, whether in our own times or at any period of the past, because the forms surviving at any given moment will have been exposed for a long succession of antecedent periods to those powerful causes of extinction which are slowly, but incessantly, at work in the organic and inorganic worlds.

Dr. Hooker, in commenting on the loss of a hundred species of plants in the course of the last three and a half centuries in St. Helena,* remarks, 'every one of these species was a

* See above, page 458.

link in the chain of created beings, which contained within itself evidence of the affinities of other species, both living and extinct, but which evidence is now irrecoverably lost.'

It is affirmed by Darwin that genera which in the present state of the globe are most dominant contain also the most variable species. It is in such genera that the formation of new races, or 'incipient species,' is most actively going on; whereas in the majority of more ancient genera and families species are fast dying out; and that such has always been the order of Nature is proved by the fact, that while certain forms are characteristic of every geological period, these same are unknown or feebly represented, whether in older strata or in formations of later date.

They who imagine that if the theory of Transmutation be true we ought to discover in a fossil state all the intermediate links by which the most dissimilar types have been formerly connected together must tacitly assume that it is part of the plan of Nature to leave to after ages permanent records of all her works, whether animal or vegetable. Yet these same objectors to the theory would hardly expect that the species of plants just alluded to as having been so recently extirpated in St. Helena have all of them left memorials of their existence in the crust of the earth. In Chapter XIV. I have treated of the fragmentary nature of the geological record,* re-affirming what I first stated in 1833, that it is scarcely possible to exaggerate the defectiveness of our archives. These records, like the existing species, are constantly wasting away before our eyes, while new deposits, containing the partial memorials of the modern fauna and flora, are now in the process of formation. But as the new strata are deposited out of sight, chiefly in the basins of seas and lakes, their origin is not so conspicuous as is the destruction of the memorials of older date.

So also, as before stated (p. 270), the dying out of old forms is more easily proved than the coming in of new ones. We might see in a large forest a full-grown tree blown down or felled by the axe every day in the year, and yet at the end of fifty years

* Vol. I. pp. 314–320.

find that the number and size of the trees in the forest was the same as before, because the daily growth of timber spread over many thousands of trees, though insensible to the eye, may every day produce a quantity of foliage and timber equal in the aggregate to that contained in a single full-grown tree. In like manner if one species die out annually, as before hinted (p. 272), the loss may be compensated by the amount of permanent change effected by Variation and Natural Selection, in the course of a single year, among thousands of species.

CHAPTER XLIII.

MAN CONSIDERED WITH REFERENCE TO HIS ORIGIN AND GEOGRAPHICAL DISTRIBUTION.

GEOGRAPHICAL DISTRIBUTION OF THE RACES OF MAN—DRIFTING OF CANOES TO VAST DISTANCES—MAN, LIKE OTHER SPECIES, HAS SPREAD FROM A SINGLE STARTING-POINT, OR LIMITED AREA—WHETHER MAN'S BODILY FRAME BECAME MORE STATIONARY WHEN HIS MIND BECAME MORE ADVANCED—GREAT ANTIQUITY OF THE MORE MARKED HUMAN RACES—GENERAL COINCIDENCE OF THEIR RANGE WITH THE GREAT ZOOLOGICAL PROVINCES—AMERICAN-INDIAN COMMON TO NEOARCTIC AND NEOTROPICAL REGIONS—MAN AN OLD-WORLD TYPE—MARKED LINE OF SEPARATION BETWEEN MALAYAN AND PAPUAN RACES—DISTINCTNESS OF NEGRO AND EUROPEAN, AND QUESTION OF THE MULTIPLE ORIGIN OF MAN—SIX-FINGERED VARIETY OF MAN AS BEARING ON THE MUTABILITY OF HIS ORGANISATION—REGROWTH OF SUPERNUMERARY DIGITS WHEN AMPUTATED—THESE PHENOMENA REFERRED BY DARWIN TO REVERSION—WHETHER MAN HAS BEEN DEGRADED FROM A HIGHER OR HAS RISEN FROM A LOWER STAGE OF CIVILISATION—GRADUAL DIMINUTION OF THE NUMBER OF LANGUAGES AND RACES—GAUDRY ON INTERMEDIATE FORMS BETWEEN THE UPPER MIOCENE AND THE LIVING MAMMALIA—RELATIONSHIP OF MIOCENE AND LIVING QUADRUMANA—OWEN'S CLASSIFICATION OF MAMMALIA ACCORDING TO CEREBRAL DEVELOPMENT—PROGRESSIVE ADVANCEMENT IN CEREBRAL CAPACITY OF THE VERTEBRATA—IMPROVEMENT OF MAN'S CEREBRAL CONFORMATION—WHETHER THERE IS ANY FIXED LAW OF PROGRESS—OBJECTIONS TO DARWIN'S THEORY OF NATURAL SELECTION CONSIDERED—GREAT STEP GAINED IF SPECIES ARE SHOWN TO BE DEVELOPED ACCORDING TO THE ORDINARY LAWS OF REPRODUCTION—CAUSE OF RELUCTANCE TO BELIEVE IN MAN'S DERIVATIVE ORIGIN.

Geographical Distribution of the Races of Man.—In this chapter I shall offer some observations on the geographical distribution of the different races of man, and consider whether, if we admit the doctrine of Transmutation as most probable in the case of the inferior mammalia, we are bound to embrace the same hypothesis when speculating on the origin of the human species.

Long before the geologist had succeeded in tracing back the signs of man's existence to a time when Europe was inhabited by species of quadrupeds, such as the elephant,

rhinoceros, bear, lion, hyæna, and others long since extinct, naturalists had already amused themselves in speculating on the probable birthplace of mankind, the point from which, if we assume the whole human race to have descended from a single stock, the tide of emigration must originally have proceeded. It has been always a favourite conjecture, that this birthplace was situated in an island within or near the tropics, where perpetual summer reigns, and where fruits, herbs, and roots are plentifully supplied throughout the year. The climate of these regions, it has been said, is suited to a being born without any covering, and who had not yet acquired the arts of building habitations or providing clothes.

'The hunter state,' it has been argued, 'which Montesquieu placed the first, was probably only the second stage at which mankind arrived; since so many arts must have been invented to catch a salmon, or a deer, that society could no longer have been in its infancy when they came into use.' * When regions where the spontaneous fruits of the earth abound became overpeopled, men would naturally diffuse themselves over the neighbouring parts of the temperate zone; but a considerable time would probably elapse before this event took place; and it is possible, as a writer before cited observes, that in the interval before the multiplication of their numbers and their increasing wants had compelled them to emigrate, some arts to take animals were invented, but far inferior to what we see practised at this day among savages. As their habitations gradually advanced into the temperate zone, the new difficulties they had to encounter would call forth by degrees the spirit of invention, and the probability of such inventions always rises with the number of people involved in the same necessity.†

Sir Humphry Davy, although coinciding for the most part in the above views, has introduced one of the persons in his second dialogue, as objecting to the theory of the human race having gradually advanced from a savage to a civilised state, on the ground that 'the first man must have inevit-

* Brand's Select Dissert. from the Amœn. Acad., vol. i. p. 118. † Ibid.

ably been destroyed by the elements or devoured by savage beasts, so infinitely his superiors in physical force.' * But this difficulty had been met, as before stated, by assigning, as the original seat of man, some island within the tropics, free from large beasts of prey. Here man may have remained for a period, peculiar to a limited area, just as some of the large anthropomorphous species are now restricted to one tropical island. In such a situation, the new-born race might have lived in security, though far more helpless than the New Holland savages, and might have found abundance of vegetable food. Colonies may afterwards have been sent forth from this mother country, and then the peopling of the earth may have proceeded according to the hypothesis before alluded to.

In an early stage of society the necessity of hunting acts as a principle of repulsion, causing men to spread with the greatest rapidity over a country, until the whole is covered with scattered settlements. It has been calculated that 800 acres of hunting-ground produce only as much food as half an acre of arable land. When the game has been in a great measure exhausted, and a state of pasturage succeeds, the several hunter-tribes, being already scattered, may multiply in a short time into the greatest number which the pastoral state is capable of sustaining. The necessity, says Brand, thus imposed upon the two savage states, of dispersing themselves far and wide over the country, affords a reason why, at a very early period, the worst parts of the earth may have become inhabited.

But this reason, it may be said, is only applicable in as far as regards the peopling of a continuous continent; whereas the smallest islands, however remote from continents, have almost always been found inhabited by man. St. Helena, it is true, afforded an exception; for when that island was discovered in 1501, it was only inhabited by sea-fowl, and occasionally visited by seals and turtles.† The islands also of Madeira, Mauritius, Bourbon, Pitcairn, and Juan Fernandez, and those of the Galapagos Archipelago, one of which is 70 miles long, were uninhabited by man when first

* Sir H. Davy, Consolations in Travel, p. 74. † See p. 457.

discovered, as were also the Falkland Islands, which is still more remarkable, since they are together 120 miles in length by 60 in breadth, and abound in food fit for the support of man.

Drifting of canoes to vast distances.—Very few of the numerous coral islets and volcanos of the vast Pacific, capable of sustaining a few families of men, have been found untenanted; and we have, therefore, to enquire whence and by what means, if all the members of the great human family have had one common source, could those savages have migrated. Captain Cook, Mr. Forster, and others, have remarked that parties of savages in their canoes must have often lost their way, and must have been driven on distant shores, where they were forced to remain, deprived both of the means and of the requisite intelligence for returning to their own country. Thus Cook found on the island of Wateoo three inhabitants of Otaheite, who had been drifted thither in a canoe, although the distance between the two isles is 550 miles. In 1696, two canoes, containing thirty persons, who had left Ancorso, were thrown by contrary winds and storms on the island of Samar, one of the Philippines, at a distance of 800 miles. In 1721 two canoes, one of which contained twenty-four, and the other six persons, men, women, and children, were drifted from an island called Farroilep to the island of Guaham, one of the Marians, a distance of 200 miles.*

Kotzebue, when investigating the Coral Isles of Radack, at the eastern extremity of the Caroline Isles, became acquainted with a person of the name of Kadu, who was a native of Ulea, an isle 1,500 miles distant, from which he had been drifted with a party. Kadu and three of his countrymen one day left Ulea in a sailing boat, when a violent storm arose, and drove them out of their course: they drifted about the open sea for eight months, according to their reckoning by the moon, making a knot on a cord at every new moon. Being expert fishermen, they subsisted entirely on the produce of the sea; and when the rain fell, laid in as much fresh water as they had vessels to contain it. 'Kadu,'

* Malte-Brun's Geography, vol. iii. p. 419.

says Kotzebue, 'who was the best diver, frequently went down to the bottom of the sea, where it is well known that the water is not so salt, with a cocoa-nut shell, with only a small opening.' * When these unfortunate men reached the Isles of Radack, every hope and almost every feeling had died within them; their sail had long been destroyed, their canoe had long been the sport of winds and waves, and they were picked up by the inhabitants of Aur in a state of insensibility; but by the hospitable care of those islanders they soon recovered, and were restored to perfect health.†

Captain Beechey, in his voyage to the Pacific, fell in with some natives of the Coral Islands, who had in a similar manner been carried to a great distance from their native country. They had embarked, to the number of 150 souls, in three double canoes, from Anaa, or Chain Island, situated about 300 miles to the eastward of Otaheite. They were overtaken by the monsoon, which dispersed the canoes; and after driving them about the ocean, left them becalmed, so that a great number of persons perished. Two of the canoes were never heard of; but the other was drifted from one uninhabited island to another, at each of which the voyagers obtained a few provisions; and at length, after having wandered for a distance of 600 miles, they were found and carried to their home in the Blossom.‡

Mr. Crawfurd informs me that there are several well-authenticated accounts of canoes having been drifted from Sumatra to Madagascar, and by such causes a portion of the Malayan language, with some useful plants, have been transferred to that island, which is principally peopled by negroes.

The space traversed in some of these instances was so great, that similar accidents might suffice to transport canoes from various parts of Africa to the shores of South America, or from Spain to the Azores, and thence to North America;

* Chamisso states that the water which they brought up was cooler, and, *in their opinion*, less salt. It is difficult to conceive its being fresher near the bottom, except where submarine springs may happen to rise.

† Kotzebue's Voyage, 1815–1818. Quarterly Review, vol. xxvi. p. 361.

‡ Narrative of a Voyage to the Pacific, &c., in the years 1825, 1826, 1827, 1828, p. 170.

so that man, even in a rude state of society, is liable to be scattered involuntarily by the winds and waves over the globe, in a manner singularly analogous to that in which many plants and animals are diffused. We ought not, then, to wonder, that during the ages required for some tribes of the human race to attain that advanced stage of civilisation which empowers the navigator to cross the ocean in all directions with security, the whole earth should have become the abode of rude tribes of hunters and fishers. Were the whole of mankind now cut off, with the exception of one family, inhabiting the old or new continent, or Australia, or even some coral islet of the Pacific, we might expect their descendants, though they should never become more enlightened than the Australians, the South Sea Islanders, or the Esquimaux, to spread in the course of ages over the whole earth, diffused partly by the tendency of population to increase, in a limited district, beyond the means of subsistence, and partly by the accidental drifting of canoes by tides and currents to distant shores.

Man has spread from a single starting-point.—The close affinity of all the races of mankind in their bodily conformation and in their mental and moral attributes, and the manner in which the most divergent varieties intermarry and blend together, require us to believe that the species was essentially in all its characters what it now is before it began to be diffused in the manner above supposed. The more we study the relations of man to the rest of the organic world, the more complete do we find his subjection to the same general laws. If, therefore, we infer that every species of animal has had a single birthplace, it is natural to expect that we shall find that man is no exception to the rule, and that he also spread over all the continents and islands from a single starting-point. But it does not follow that all are descendants of a single pair. Indeed, if we embrace the doctrine of Transmutation, the process by which a new species comes into being is by no means simple, and it is not easy to form a precise idea of its elaboration during that period of transition when certain varieties tending in a given direction are repeatedly getting the better of others in the struggle for life.

Under the constant influence of the same external conditions, the characters of such varieties become intensified during many successive generations, and when at last they are fixed and permanent the ancestral type may have perished, or in some cases may survive in certain stations, the intermediate forms having been absorbed into one or other of the two extremes. During a period when the powers of Variation and Selection are so active, a considerable number of individuals closely allied in their organisation will intermarry freely and multiply within a limited geographical area, and will transmit the same peculiarities of bodily and mental structure to their offspring. When, by this process, a large homogeneous population has been formed, and their characters have become fixed by inheritance, it will be long before subsequent changes of climate, soil, food, and other conditions, and, in the case of man, customs and institutions, will cause any marked deviations from the normal type.

That it should be so difficult for us to picture to ourselves the manner in which a species may be elaborated by Variation and Selection, need not surprise us when we consider how hard it is to obtain a clear idea of the growth and establishment of a new language, even when we are sure that the same has originated only a few centuries before our time. In the case of the English tongue, for example, it would not be easy to fix upon the exact year or generation when it was formed, or to follow it through its various transitional phases when the Anglo-Saxon stock was becoming modified by incorporating into it French, Danish, and Latin terms and idioms, or when new modes of pronunciation were coming into vogue or new and original expressions invented. The unity and permanency of character which finally sprang out of the blending together of such heterogeneous materials is a singular phenomenon, and the want of pliancy of the same language when transplanted into distant regions is also remarkable. The modifiability of the language and its tendency to vary never cease, so that it would readily run into new dialects and modes of pronunciation if there were no communication with the mother country direct or indirect. In this respect its mutability will resemble that of species, and it can

no more spring up independently in separate districts than species can, assuming that these last are all of derivative origin.

Whether man's bodily frame became more stationary when his mind became more advanced.—Mr. Wallace, when commenting on the distinctness of the leading races of mankind, especially the Caucasian and Negro, and on the constancy of characters maintained by these last for 4,000 years, as proved by old Egyptian paintings, suggests that at some former period man's corporeal frame must have been more pliant and variable than it is now; for, according to the observed rate of fluctuation in modern times, scarcely any conceivable lapse of ages would suffice to give rise to such an amount of differentiation. He therefore concludes that when first the mental and moral qualities of man acquired predominance, variations in his bodily form ceased to be preserved and accumulated by Natural Selection, because he was enabled to meet all new exigencies springing out of new conditions of existence by inventing new weapons, by clothing himself and building houses to protect him against the inclemency of the weather, by making use of fire to render palatable and nutritious animal and vegetable substances, and above all by his powers of social combination. Instead of the form of his limbs being modified or acquiring more agility and strength, instead of his sight or hearing becoming more acute, his body would remain stationary while his intellectual faculties would continually improve. *

Before, however, we embrace the views here set forth, we must be sure that we are not underrating the vastness of the time which it may possibly have taken for races so different as the European and Negro to diverge from a common type. Broca, in his work on Anthropology, when speaking of the paintings preserved in Egyptian temples nearly 4,000 years old, says that, besides Negroes and Greeks, there are representations of Jews, Mongols, Hindoos, and natives of the Valley of the Nile, proving that all these types were then as distinct as they are now. He nevertheless thinks that

* Human Races, &c. Anthropological Review, May 1864, p. clviii. Also, Contributions to Natural Selection, pp. 311–317.

climate, social condition, alimentation, and mode of life may have determined originally the diversity of races, although it is evident that three or four thousand years is but a minute fraction of the time required to bring about such wide divergence from a common parent stock.

Mr. C. L. Brace, in his answer to Mr. Wallace, has remarked that when members of the Anglo-Saxon race have in the course of the last two centuries colonised a distant country, they have, as in the United States of America, deviated in an appreciable degree from the original type, in spite of the frequent intermarriage of the new settlers with emigrants coming from the mother country. 'The form,' he says, 'has become more angular and muscular, the complexion darker, and the face longer and thinner. The intellectual and moral powers of the Anglo-American have not been deficient, and yet they have not preserved him from variation.' It is also very commonly asserted that in a few generations the English settlers in Australia have varied somewhat after the manner of the Anglo-Americans. Grant that even a slight change can be superinduced in two centuries, what may not thousands of centuries have effected when the new settlers were wandering into countries where the conditions were far more dissimilar than those of England, North Africa, and South Australia?

We may, however, concede to Mr. Wallace that when first mankind emerged from its primitive dwelling-place and began to people the unoccupied continents and islands, the formation of marked races may have proceeded at a somewhat faster rate than now. After having been for a long time as strictly confined to one district as are now the chimpanzee or orang-outang, being still in a state of ignorance and barbarism somewhat lower than that of the Australian savage or the Andaman islander, man may have spread in scattered hunter-tribes over new latitudes, often encountering very ungenial climates in regions where food was abundant. Under such circumstances the mortality of the population would be great, and Natural Selection very active in giving a preference to certain varieties over others. In Great Britain and Belgium it has been shown by statistical returns that about

one-tenth of the population die before they are a month old, and one-fourth in early childhood. If in the newly settled territories the transitions from the extremes of heat and cold were frequent, those individuals who had weak lungs would be the victims, whereas in other regions where the temperature was very equable throughout the year, the same persons might be the most healthy and most likely to grow up and become the progenitors of the race destined to people the newly occupied district. So of other variations—in some cases a darker skin, in others a lighter complexion, might be most favourable, but many generations must pass away before a combination of characters best suited to the surrounding conditions would be attained.

Coincidence of the range of the more marked human races with the great zoological provinces.—Professor Agassiz has called attention to the important fact, that each of the more marked races of the human family, such as the white race, the Chinese, the New Hollanders, the Malays, and the Negroes, is limited to some great zoological province. This circumstance, he remarks, shows most unequivocally the intimate relation existing between mankind and the animal kingdom in their adaptation to the physical world. The same naturalist, however, has scarcely laid sufficient stress on one marked exception to this rule, namely, that over the whole continent of America south of the Arctic zone (or the region which is inhabited by Esquimaux) all the numerous tribes of Red Indians have the same physical character and are of one and the same race. * Dr. Morton had already declared this to be the case after studying the craniological characters of the American Indians from Canada to Patagonia. Nevertheless this continent comprises two of the great zoological regions before defined (p. 337) as the Neoarctic and Neotropical. On independent grounds Mr. Henry W. Bates has arrived at the conclusion that the Red Indian must have immigrated in comparatively modern times into the hot regions of equatorial America. Even the European, he says, bears exposure to the sun or to unusually hot weather quite

* Agassiz, Diversity of Origin of the Human Races. Christian Examiner, July 1850.

as well as the Indians, while the Negro is far better suited to the same climate, for he escapes many epidemic diseases incidental to hot latitudes which cause great havoc among the Indians. The latter, according to Mr. Bates, lives as a stranger in his own country, the valley of the Amazons. His constitution was not originally fitted, and has not since his immigration become perfectly adapted, to the climate of tropical America.*

We have as yet no geological data to enable us to determine the relative antiquity of man in the Old and New Worlds. Some fossil remains of our species found in the valley of the Mississippi imply, if their geological position has been correctly ascertained, that man was contemporary with many extinct quadrupeds and inhabited that region before it underwent some of its latest geographical changes. † But as a matter of speculation, if we assume that mankind, like every other species, has had but one birthplace, and if we also suppose him to have been derived from some nearly allied prototype, we must incline to the belief that the peopling of America took place at a later period than that of the Old World; for man, as has been truly said, is an 'Old-World type,' his bodily structure, as before observed (p. 333), being closely related to that of the quadrumana of Africa and Asia, and differing widely from all the species of the Western Hemisphere. But the first settling of mankind in America, though a comparatively modern event, may still date back as far as the Paleolithic period of Western Europe. Some of the latest changes in the valley of the Mississippi and its tributaries may have taken place since the remains of man and of some extinct animals were buried in superficial deposits, yet throughout the period of these geographical changes the chain of the Andes may have been always continuous from Canada to Patagonia, and may have facilitated the spread of a single race from one end of the continent to the other.

Mr. Wallace in his memoir on Man in the Malay Archipelago,‡ has explained how nearly the line *a*, *b* (map, fig. 138,

* Bates, Naturalist on the Amazons, vol. ii. p. 200.

† Lyell, 'Antiquity of Man,' p. 200.

‡ Read at Brit. Assoc., Newcastle, 1864. See also Malay Archipelago, chap. xl.

p. 350), which separates the regions of the Indian and the Australian faunas, agrees with the geographical boundary line *c*, *b* (ibid.) dividing the habitations of the Indo-Malayan and the Papuan races. He describes the typical Malayan race, found almost exclusively in the western half of the archipelago, as of a light reddish brown colour with a more or less olive tint, hair black and straight, the face almost destitute of beard, the stature below the average European, while the Papuan race is much darker, sometimes almost as black as the Negro, the hair growing in tufts and frizzly, the face adorned with a beard, the stature equal to that of the European. The intellectual and moral characteristics of the two races are also described as strongly contrasted. These Papuans are found in New Guinea, while the Malays inhabit Borneo, two large islands almost exactly agreeing in climate and physical features, and within 300 miles of each other, and yet in which there is a total diversity of animal productions as well as a marked distinctness in the races of man. If we assume that these two races came originally from a common stock, we must suppose that they have been each of them separately exposed for hundreds of generations to a distinctness of external conditions analogous to that which, according to the theory of Transmutation, has, in the course of a much longer period, produced the discordance of species observed in the Indian and Australian regions.

Distinctness of Negro and European, and question of multiple origin of man.—It must be admitted, however, that we cannot so easily account for the differentiation of the Papuan and the Malay races as we can understand how the Negro acquired characters so different from those of all other members of the human family. For the natural barriers of the Ethiopian province, with the ocean on three sides and the great desert (submerged in Pliocene times) on the fourth, may well be supposed to have cut off for an indefinite lapse of ages a barbarous population from all intercourse with the rest of mankind, and to have given to peculiar external conditions an opportunity of fixing certain variations and forming a race without parallel in other parts of the world. The divergence, indeed, of the Negro from the European in the colour of his skin,

the texture and mode of growth of his hair, his features, the proportions of his limbs, and the average size of the brain, has led some naturalists to maintain that he is more than a mere variety of mankind, and ought to rank as a separate species.

Professor Agassiz, without going so far, believes nevertheless that the parent stocks from which these and other leading varieties have descended were originally distinct. According to him, a great number of individuals of each of the principal races of man were called into being when the race was created possessing all those characters which their posterity afterwards inherited; just as the same author imagines that a great many representatives of each species of animal, especially of species having social habits, were created in large numbers, so as at once to people the whole region which they were destined to inhabit. This theory has at least the merit of being consistent with itself, and relieves the opponents of transmutation from the dilemma of explaining why, if so great a divergence from a parent type as that of the white man and negro can take place, a like modifiability should not be able, in the course of ages, to go a step farther, and give rise to differences of specific value. That the races of mankind should never have diverged so far as to become incapable of intermarrying and producing fertile offspring is quite intelligible, if we consider the manner in which tribe wars against tribe, and how the inhabitants of the temperate and colder regions have continually invaded and overpowered the more indolent and less progressive tenants of tropical latitudes. These conquests explain the blending at the point of contact of one race into another, which has led many naturalists to affirm that, instead of the five principal types of Blumenbach, there are fifty, if not more than a hundred races, each of which has had its own Adam and Eve.

Six-fingered variety of man as bearing on the mutability of his organisation.—As to the supposed want of flexibility in the bodily structure of man ever since the Paleolithic period, we ought to bear in mind that according to the theory of transmutation we can only expect variations in those parts of his organisation to be perpetuated, the improvement of

which would be useful to the individual or tribe giving them an advantage in the struggle for life. We have seen (page 299), that the experiments of the breeder and horticulturist prove that one part of the organisation of an animal or plant may be greatly altered by selection, while other parts which are neglected remain unchanged or do not vary in a perceptible degree. But the organ the variation of which would be most important in the case of man is the brain, and it is on cerebral development that Natural Selection would operate most effectively. Before considering whether, in the course of thousands of generations, some favourable modifications may not have taken place in this organ, giving to one race an advantage over others, it may be well to allude to a singular deviation from the normal standard which has been observed in man, and some other of the mammalia, and which has deservedly attracted much attention. This deviation consists in the occurrence of six, instead of five digits, of which examples are found in the dog and the cat as well as in human beings. Mr. Darwin, after having tabulated the cases of 46 persons with extra digits on one or both hands or feet, which he found recorded in various works or which had been privately communicated to him, ascertained that in this number, 73 hands and 75 feet were thus affected, proving, in contradiction to previous opinions, that the hands are not more frequently affected than the feet. Professor Huxley cites in detail from Réaumur the case of a Maltese couple named Kelleia, who, having hands and feet constructed on the ordinary human model, had born to them a son, Gratio, who possessed six perfectly movable fingers on each hand, and six toes, not quite so well formed, on each foot. This son married a woman with the ordinary pentadactyle extremities, and of their children one had six fingers and six toes, and the others were of the normal type. The six-fingered son had three out of four of his children six-fingered. But what is more remarkable, two of Gratio's children of the normal type having married five-fingered wives or husbands, nevertheless reproduced in the next generation the six-fingered variety. Thus, although in each case one parent and sometimes both were five-fingered, the six-fingered variety per-

sisted down to the grandchildren of Gratio. If, observes Professor Huxley, some of these last had been matched with their cousins having the same abnormal structure, we cannot doubt that a six-fingered and six-toed race would have been perpetuated. In these cases it usually happens that the supernumerary digit is supported on a metacarpal bone, and furnished with all proper muscles, nerves, and vessels, being so perfect as to escape detection, unless the fingers are actually counted. Additional digits, says Darwin, have been observed in negroes as well as in the white races.

The frequent re-growth of supernumerary digits after they have been cut off is another extraordinary fact which must not be lost sight of by those who are disposed to speculate on the nature and cause of this phenomenon. In one instance, that of a person now living (1868), the additional finger, when the infant was about six weeks old, was removed at the joint, and as soon as the wound healed, the digit began to grow, on which the operation in about three months was repeated. when the finger was once more reproduced including a bone. In another example cited by Dr. Carpenter of a thumb double from the first joint, the lesser thumb, which was furnished with a nail, was removed, but it grew again and reproduced a nail.* Mr. Darwin regards these supernumerary digits in man as retaining to a certain extent an embryonic condition, and resembling in this respect the normal digits and limbs of the lower vertebrate classes which are so prone to reproduction. Spallanzani cut off the tail and legs of the same salamander six times successively, and Bonnet cut them off eight times, and they were always renewed. The pectoral and tail-fins of many freshwater fish having been cut off have been perfectly restored in about six weeks' time. Fishes have sometimes in their pectoral fins more than five, sometimes as many as twenty, metacarpal and phalangeal bones forming so many rays, and occasionally bearing bony filaments, which together clearly represent our digits with their nails. So again in certain extinct reptiles, the Ichthyopterygia, 'the digits may be seven, eight, or nine in number, a significant

* Darwin, 'Variation,' vol. ii., p. 294.

mark,' says Professor Owen, 'of piscine affinity.'* Mr. Darwin therefore suggests that the excess in number and the power of re-growth of the supernumerary digits in man may be an instance of reversion to an enormously remote and multidigitate progenitor of very inferior grade.† As the number five is so strictly adhered to in the digits of all the higher vertebrata, and is at least never exceeded as a rule in any living reptile, bird, or mammal, the excess above alluded to in human digits is generally regarded as a monstrosity, the more so because, although six is the more common variety, yet there are sometimes from seven to more than ten fingers or toes, more or less perfect, on the same hand or foot, and occasionally less than five. Certainly this deviation from the ordinary standard, as well as the re-growth of the amputated limb, does not point in the direction of progressive improvement. If it be looked upon as a malformation occasionally shared by other mammalia, it only adds one more to innumerable other bonds of connection by which the inferior animals and man are united, whether in the perfection, or the occasional imperfection, of their organisation. One remarkable example of such bonds of affinity has been lately adduced by Mr. Darwin in his 'Descent of Man.' In the Quadrumana and Carnivora there is a passage near the lower end of the humerus, called the supra-condyloid foramen, through which the great nerve of the fore-limb passes, and often the great artery. Now occasionally this foramen occurs in man with the nerve passing through it, and it is remarkable that the percentage of the occurrence of this variation is greater in ancient than in modern races in the proportion of nearly 30 to 1. This has been ascertained by the examination of large numbers of arm-bones of the Bronze and Reindeer periods, and Mr. Darwin remarks, that one chief cause of this nearer approach of ancient races to the type of structure of the lower animals, seems to be 'that ancient races stand somewhat nearer in the long line of descent to their remote animal-like progenitors than do the modern races.' ‡

* Darwin, 'Variation,' vol. ii., p. 294.

† See above, p. 292, on Darwin's theory of Pangenesis.

‡ 'Descent of Man,' vol. i., p. 28.

Whether man has been degraded from a higher or has risen from a lower stage of civilisation.—All our recent investigations in Europe into the state of the arts in the earlier Stone age, lead clearly to the opinion that at a period many thousands of years anterior to the historical, man was in a state of great barbarism and ignorance, exceeding that of the most savage tribes of modern times. He was evidently ignorant of metals, and of the arts of polishing stone implements and of making pottery. Sir John Lubbock, in discussing the question whether our ancestors have been degraded from an original stock which was more highly advanced in knowledge and civilisation, or has risen from a lower state, observes that no fragment of pottery has been found among the natives of Australia, New Zealand, and the Polynesian islands, any more than ancient architectural remains, in all which respects these rude tribes now living resemble the men of the Paleolithic age. When pottery, he says, is known at all, it is always abundant, and though easy to break, it is difficult to destroy. It is improbable that so useful an art should ever have been lost by any race of man. The theory, therefore, that the savage races have been degraded from a previous state of civilisation may be rejected. 'Civilised nations long retain traces of their ancient barbarism, whereas barbarous ones retain no relics of a previous more advanced state. The stone knives used by the Egyptian and Jewish priests in religious ceremonies, after metal was in use for secular purposes, point to an antecedent period when such stone implements were in general use. They would long be regarded as sacred, and there would be a reluctance to use a new substance in religious ceremonies.' *

Some have wished to found an argument in favour of the superior mental endowments of the earliest races of mankind, by pointing out that the Sanscrit, and some others of the most ancient languages of Asia, are very artificial in their grammatical construction and rich in abstract terms. But the nations speaking these tongues will be regarded by every geologist as modern when compared to the men of the Paleolithic age. In tracing back the course of human events we

* On the Early Condition of Man, Sir John Lubbock. British Assoc. 1867.

should first find a period when scattered migratory hordes in the hunter state were spreading over Asia, and then a still anterior period when one small area of land (possibly now in great part submerged in the Indian or Pacific oceans) contained the primitive stock from which they all have ramified, and we may be sure, if the theory of transmutation be true, that such progenitors of mankind had a scantier vocabulary than the humblest savage known to us. They would have been unable to count as far as the fingers on one hand, and would not have invented a single term expressive of an abstract idea. When the first emigrants were spreading over a wide continent, they would separate into small communities, each of which would gradually acquire a language of its own, but as often as one tribe became more powerful than its neighbours, it would conquer them and absorb into itself those who were not exterminated, imposing its language on the conquered, yet sometimes borrowing from them some terms and expressions. It is found that the number of independent languages spoken in a continuous tract of land is great in proportion to the barbarism of the natives. Dominant tribes, as they multiply and advance in civilisation and power, spread a single language over a vast area. The Chinese for example, several thousand years before our time, constituting a third of the population of the globe, imposed on nearly the whole of their empire one language, though diverging, it is true, into many dialects. How long a time it required for one race thus to obtain supremacy over a large part of Asia, we know not, but we may look forward to the time when the Europeans, especially the Anglo-Saxon race, will in like manner spread over still larger areas, displacing the aboriginal tribes of America, and, like their predecessors the Red Indians, spreading from the Arctic Region to Patagonia, so that one race and perhaps one language may eventually prevail throughout the Neoarctic and Neotropical provinces before alluded to.

It may seem to us almost incredible now that the progress of the arts has given us such powers of locomotion, such facilities of traversing continents and circumnavigating the globe, to say nothing of exchanging ideas instantaneously

with the inhabitants of the remotest regions, that nations, even after they had advanced far in civilisation, could remain so isolated as we know them to have done. How the Greeks, for example, in spite of their extraordinary genius and their spirit of commercial enterprise, could have continued so ignorant of the geography of countries only a few hundred miles distant from the coasts of the Mediterranean and Black Seas. The superior power which science confers is always increasing in a geometrical ratio, so that the displacement of the weaker by the more civilised nations is accelerated to an extent without parallel in the history of the past. Hence in future there will be a greater blending of races, and a constant tendency towards the establishment of one race and one language throughout the globe. It seems probable that the divergence from a common stock reached its climax, physically and psychologically, in the formation of the Caucasian and Negro races. If, therefore, we consider this differentiation as amounting only to one of race, it seems to follow that two rational species descending from a common parentage cannot coexist on the globe. In embracing this conclusion, however, we are not precluded from entertaining the opinion that the descendants of the same rational progenitors, if compared at two very distant times, may differ as much as might entitle them to rank as distinct species.

M. Gaudry on intermediate forms between the Upper Miocene and living mammalia.—The relationship of man to a supposed antecedent species nearly allied in bodily structure, offers at present to the geologist a field of somewhat unprofitable speculation, so long as the Pliocene and Post-Pliocene formations of tropical Africa and India are still unexplored. We are only beginning, by aid of paleontology, to trace back the passage through a series of gradational forms from the living mammalia to those of the Pliocene and still older Miocene periods. But in this department of osteology, the evidence already obtained since the time of Cuvier, in favour of transmutation, is certainly very striking. By no naturalist has its bearing been more clearly pointed out than by M. Gaudry, who, under the influence of the great teachers

who preceded him, entered on the enquiry with a theoretical bias directly opposed to the conclusions which he now so ably advocates. In his luminous memoir on the fossil bones found at Pikermi, near Mount Pentelicus, fourteen miles east of Athens, he has pointed out the transition through many intermediate forms of Upper Miocene species to others of Pliocene and Post-Pliocene date, showing how each successive discovery has enabled us to bridge over many gaps which existed only twenty or thirty years ago. Having myself had the advantage of seeing the original specimens collected by this zealous geologist, and now in the museum of Paris, and having had the connecting links supplied by species obtained from other parts of the world laid before me, I have been able the more fully to appreciate the force of the evidence appealed to in favour of transmutation. But all who study M. Gaudry's memoir may form an independent opinion for themselves, by a glance at the genealogical tables of certain family types, in which the gradation of Miocene through Pliocene and Post-Pliocene to living genera and species is traced.

In the list of proboscidians, for example, we behold chronologically arranged more than thirty distinct species, beginning with the mastodons of the Middle Miocene period, found in France, and continued through those of the Upper Miocene of Ava, the Sewalik Hills, Pikermi, and Eppelsheim, to the Pliocene forms of Southern India, Italy, and England, where both the mastodons and elephants occur. Finally we are conducted to the Post-Pliocene or quaternary species of Europe and America, till we end with the two existing elephants of India and Africa. Again of the rhinoceros family, besides the five living species, fifteen extinct ones are enumerated, and in addition to these, some generic forms of older or Eocene date, belonging to the same great family. The fossil pedigree of the horse tribe is equally instructive, traced from the Middle and Upper Miocene Hipparion of France, Germany, Greece, and India, through the Pliocene and Post-Pliocene equine species of Europe, India, and America, to the living horse and ass. But the twelve equine species referred by Leidy to seven genera detected in the

valley of the Niobrara in Pliocene and Post-Tertiary formations,* are omitted from this table as not having been yet described in sufficient detail, and they would certainly, if inserted in M. Gaudry's table, help to fill up many a hiatus between the forms which he has recognised. The pig family, as well as some carnivora, such as the hyæna, have also furnished ample materials in illustration of the same law of a gradual change of structure.

Even the quadrumana are beginning to afford proofs of the manner in which the existing apes have ramified from their extinct prototypes, although our information respecting them, whether from Pikermi or elsewhere, has been hitherto almost exclusively derived from extra-tropical latitudes, where there are now no living representatives of the order. Only fourteen species of the ape and monkey tribe have as yet been detected in a fossil state, and each of these has usually furnished but a few bones of its skeleton to the osteologist. Yet they have not failed to throw much light on the transmutation hypothesis. The Dryopithecus of the Miocene era of the south of France, though specifically distinct from any ape now existing, comes so near to the living Gibbon, or long-armed ape, as not to deserve, in Professor Owen's opinion, the separate generic rank assigned to it by Lartet. All the other fossils of Europe and Asia have an affinity to living species or genera of the Catarrhine division, and those of America, found in Brazilian caves, to the Platyrrhine.

As to the Mesopithecus of Pikermi, the skeleton is almost complete, more so than that of any other fossil ape yet brought to light. It differs generically from any living Indian form, not so much by presenting any novel features in its structure as by combining characters which now belong to two distinct Indian types. For, says M. Gaudry, one might say that the living Semnopitheci of India have borrowed their skulls from this Miocene type, while the living Macaci have borrowed from it their limbs. 'In how different a light,' exclaims this eminent paleontologist, 'does the question

* See above, p. 340.

of the nature of species now present itself to us from that in which it appeared only twenty years ago, before we had studied the fossil remains of Greece and the allied forms of other countries; how clearly do these fossil relics point to the idea that species, genera, families, and orders now so distinct, have had common ancestors!'—'The more we advance and fill up the gaps, the more we feel persuaded that the remaining voids exist rather in our knowledge than in nature. A few blows of the pickaxe at the foot of the Pyrenees, of the Himalaya, of Mount Pentelicus in Greece, a few diggings in the sandpits of Eppelsheim, or in the Mauvaises Terres of Nebraska, have revealed to us the closest connecting links between forms which seemed before so widely separated! How much closer will these links be drawn when paleontology shall have escaped from its cradle!'*

Many of the most cultivated literary critics, and some eminent mathematicians, have shown, in the discussions which have arisen on the origin of species, an entire incapability of weighing and appreciating the evidence for and against transmutation, and this chiefly for two reasons: first, they have never been called upon, as classifiers in natural history, practically to decide whether certain forms, fossil or recent, should rank as species or as mere varieties—a point on which the most eminent zoologists and botanists often disagree; secondly, they are quite unconscious of the fragmentary nature of the record with which the geologist has to deal.† To one who is not aware of the extreme imperfection of this record, the discovery of one or two missing links is a fact of small significance; but to those who are thoroughly imbued with a deep sense of the defectiveness of the archives, each new form rescued from oblivion is an earnest of the former existence of hundreds of species, the greater part of which are irrecoverably lost.

Progressive development in the cerebral conformation of the vertebrata, including man.—I have already remarked when combating the notion that man in his corporeal structure has arrived at a fixed and stationary condition, that we have

* Gaudry, Animaux Fossiles de Pikermi, 1866, p. 34.

† See above, vol. i., p. 314.

no right to make such an assumption, until we have acquired a more definite idea of the number of centuries which it took for the most marked of the human races to diverge, in different directions, so far from a common type. The rate of change generally in the animal and vegetable kingdoms is slow and insensible, and naturalists have never yet witnessed the formation of any one of the wild races which they regard as mere geographical varieties. They know not how many thousand generations it may have required to produce such changes; but we cannot infer in their case, or in that of man, that the era of the immutability of species has arrived. If the organisation of man has been modified in comparatively modern times, it is probably, as before hinted, in his cerebral development that variation has been manifested.

Linnæus declared that he could not distinguish man generically from the ape, and Professor Owen has spoken of the 'all-pervading similitude of structure—every tooth, every bone, being strictly homologous'—yet the same great anatomist considers man's superior cerebral development as entitling him to be placed in a sub-class apart from all the other mammalia. He has proposed a new classification of the highest division of the vertebrata with reference to the characters of their brain, and its greater or less resemblance, in volume and structure, to that of man. Some have objected, not perhaps without reason, that every such attempt to classify the animate creation by reference to a single organ, or one set of characters, has failed, and that in order to obtain a natural system of arrangement, we must duly consider the combined claims of as large a part as possible of the whole organisation. Nevertheless the extent to which cerebral conformation, taken by itself, has enabled Professor Owen to place the genera and orders of mammalia in an ascending scale, shows how predominant is the importance of the brain, and the intimate connection of this mysterious organ with mental power. We see the monotremes (the Echidna and duck-mole) take the lowest place in the scale, followed by the marsupials, all having brains the most dissimilar in capacity and form from that of man; while the quadrumana take the highest place measured by the same

standard, the family to which the chimpanzee and gorilla belong being at the head of the long list of tabulated genera and orders. It will also be observed that the bats, instead of maintaining the leading position among the 'Primates' which they occupied in the Linnæan classification, are assigned to a different and inferior sub-class, far more in accordance with their relative intelligence.

If we go still farther and compare the mammalia with the fish, or the lowest class of the vertebrata, we find a continuance of the same descending scale in accordance with a diminution in the volume of brain, as well as in a lessened concentration of the nervous system in one part of the animal; for the farther we recede from the human type, the smaller is the proportionate quantity and weight of the brain as compared to the spinal marrow. It is true that in attempting to apply these rules in detail the anatomist is often at fault, because he finds that in any given group of animals the larger species have proportionately smaller brains, or, in other words, the mass of the brain does not increase in the same ratio as the general bulk of the animal. Still the general proposition before laid down holds good, that the degree of intelligence and mental power enjoyed by the inferior animals increases with the increase of their cerebral capacity, and with the resemblance in the structure of their brain to that of man.

If we take the Hottentot as the least advanced variety of the negro type, we find not only the volume of the brain to be far below that of the average of the European, but that the two hemispheres are more symmetrical, and that in this and every peculiarity in which it deviates from the Caucasian standard, it approaches nearer in character to the Simian brain. The theory therefore of progressive development and transmutation would lead us to anticipate that the human skull of the Paleolithic period would prove to be more pithecoid than the cranium of any living race. Our data are as yet too scanty to allow of our drawing safe conclusions from the fossil remains of the era in question, for the Neanderthal skull may be an exceptional variety, as may some other remains of a somewhat ape-like character, lately brought to

light by M. Dupont from a deposit containing the relics of extinct mammalia in the Belgian caves. It may also be said that there is no reason why the Paleolithic cranium should be much if at all inferior to that of an Australian, for the state of the arts in the Paleolithic period accords well with that phase of advancement which the Australian and some other savage tribes had reached when they first become known to Europeans.

In the ninth chapter of the first volume, a brief summary was given of the evidence in favour of the successive appearance in chronological order of fish, reptile, bird and mammal, and lastly among the mammalia, the coming in of those anthropomorphous species which most resemble man in structure. If we then regard the advent of man as the last and culminating point attained in this continuous series of developments, we may well imagine that, during the transition from the quadrumanous to the human organisation, the brain was that part which underwent the chief modification. And when its growth and improvement had once conferred on man a decided superiority over the brutes, it would continue to be the organ which would go on improving, so as to give one race an advantage over others in the struggle for life.

Even if the paleontologist had obtained fossil crania of an age immediately antecedent to the Paleolithic, it might be difficult for him to derive from them a knowledge of the successive steps made in an ascending scale, if, as some physiologists suspect, the quality of the brain has often more to do than its quantity with intellectual superiority. But although size alone may be no safe criterion of relative mental power, it is undeniable that the skulls of a hundred individuals of transcendent ability would exceed in their average dimensions the skulls of an equal number of persons of inferior mental power. Whether the brain, like any other organ, gains strength by exercise, and whether an improvement thus acquired in the intellectual faculties may be handed down to the offspring by inheritance, are still matters of controversy. But no one is disposed to dispute that, if some modification of an organ, or instinct, be produced by what is called

'spontaneous variation,' there is a decided propensity in the new structure or attribute to perpetuate itself by inheritance, as in the case of the six-fingered variety of man, before mentioned (p. 481), or the stunted legs of the Ancon sheep (p. 314).

If, therefore, it be part of the plan of Nature that living beings should occasionally give birth to varieties in some slight degree more perfect in the specialisation of their parts and organs, or in the perfection of an organ, instinct, or mental faculty, than had been enjoyed by any of their predecessors, Natural Selection will ensure the eventual success of such individuals in the struggle for life. When Mr. Darwin says that he does not believe in a law of necessary development, he means that simple and unimproved structures may sometimes be best fitted for simple conditions of life, and that even a degradation instead of an advance in structure may occasionally be advantageous. Nevertheless, in the long run, there will be a tendency, in the higher and more perfect organisms, to survive and multiply, not at the expense of the lower, with most of whom they will never come into competition, but at the expense of those which are most nearly allied to them. The repeated failure of particular varieties having organs and attributes somewhat superior to those of any of their progenitors, by no means implies that the final predominance of such organisms is left to chance. It suffices that there should be a power in Nature, capable of giving rise to individuals in advance of all which have preceded them, and it then becomes simply a question of time how soon the more improved varieties will prevail. Their final success is certain, though many adverse circumstances may retard the rate of progress.

Suppose a human infant endowed with intellectual capacity superior to that of any one previously born into the world; it is as liable to be cut off in childhood as one less gifted, but it has also an equal chance of growing up, and if it attains maturity it will promote the advancement of the tribe to which it belongs, inventing perhaps some warlike weapon or better laws and institutions, and there will be a great probability of some of the children of such an individual inheriting an

amount of talent above the average of their generation. The more civilisation advances the less will mere bodily strength and acuteness of the senses confer social superiority. But still, as Darwin says, there is no fixed and necessary law of progress. The institutions of a country may be so framed that individuals possessing moderate or even inferior abilities may have the best chance of surviving. Thus the Holy Inquisition in Spain may for centuries carefully select from the thinking part of the population all men of genius, all who dare to question received errors and who have the moral courage to express their doubts, and may doom them by thousands to destruction, so as effectually to lower the general standard of intelligence. But such exceptional institutions will not arrest the onward march of the human race. They will only depress one nation, causing it to decline in knowledge, power, wealth, population, and political influence, and prepare for the day when it will be conquered by some other people in which freer scope has been given to intellectual progress.

Objections to Darwin's theory of Natural Selection.—The Duke of Argyll, in his work on the 'Reign of Law' (1867), has made some valuable criticisms on Mr. Darwin's theory of Natural Selection. After observing that we know nothing of the natural forces by which new forms of life are called into being, he says that if there were evidence that the new could be developed from the old, he cannot see why there should be any reluctance to admit the fact.* But he denies that sufficient evidence in support of such a theory has yet been adduced. The introduction, he admits, of new species 'to take the place of those which have passed away, is a work which has been not only so often but so continuously repeated that it does suggest the idea of having been brought about through the instrumentality of some natural process.'† This process, or 'the adaptation of forces which can compass the required modifications in animal structure in exact proportion to the need of them, is in the nature of creation.' But Mr. Darwin, he says, does not pretend to explain how new forms first appear, but only how when they have ap-

* Reign of Law, p. 227. † Ibid. p. 228.

peared they acquire a preference over others. He also reminds us that Mr. Darwin frankly confesses that our ignorance of the laws of variation is profound: yet, says the Duke, he seems sometimes to forget this and to speak of Natural Selection as if it could account for the origin of species, whereas, 'according to his own definition, it can do nothing except with the materials presented to its hands. It cannot select except among things open to selection. It can originate nothing; it can only pick out and choose among the things which are originated by some other law.'* To speak therefore of Natural Selection as 'producing' certain modifications of structure or new organs, and as 'adapting' them, is to ascribe to it results which it cannot bring about, and 'the cause of which we cannot even guess at.'†

To me it appears that these criticisms are fairly applicable to those passages in Mr. Darwin's 'Origin of Species,' in which Natural Selection is spoken of as capable of bringing about any amount of change in the organs of an animal provided a series of minute transitional steps can be pointed out by which the transmutation may have been effected. Thus, for example, if some one of the invertebrate animals has a membrane or tissue without a single nerve, yet sensitive to light, while another creature such as an eagle is furnished with a perfect eye in which there is an apparatus for concentrating the luminous rays, and for refracting pictures of external objects with optic nerves to convey these images to the brain, it is suggested that we may understand how this perfect organ may have been 'formed by Natural Selection' if we can only find in Nature a series of animals which have organs of vision exhibiting all the intermediate grades of structure between the two extreme forms above mentioned. But in reality it cannot be said that we obtain any insight into the nature of the forces by which a higher grade of organisation or instinct is evolved out of a lower one by becoming acquainted with a series of gradational forms or states, each having a very close affinity

* Reign of Law, p. 230. † Ibid. p. 254.

to the other. Even if we could discover geological evidence that every modification between a mere power of sensation like that of a sponge and the intelligence of an elephant had been represented by every intermediate degree of instinct and capacity, and that beings endowed with faculties more and more perfect had succeeded each other in chronological order according to their relative perfection, like the successive stages in the development of the embryo from a simple germ-cell to the infant mammifer, still the mystery of creation would be as great, and as much beyond the domain of science, as ever. It is when there is a change from an inferior being to one of superior grade, from a humbler organism to one endowed with new and more exalted attributes, that we are made to feel that, to explain the difficulty, we must obtain some knowledge of those laws of variation of which Mr. Darwin grants that we are at present profoundly ignorant.

Mr. Mivart in a more recent work (1871) on the 'Genesis of Species,' while he is in favour of the theory of Evolution as distinct from Special Creation, has made good use of his extensive knowledge of Natural History and Comparative Anatomy in adducing cases of structure, such as the baleen of the whale, the mammary glands of the mammalia, and the eyes and auditory organs of the cephalopoda, which seem to him to point to a limit of the power of Natural Selection and the intervention of some unknown law or laws of still higher generality. To all these Mr. Darwin has severally replied at some length in the sixth edition of the 'Origin of Species' (1872), and I cannot do better than refer the reader to that work. But as the independent development of a perfect eye in the cephalopoda and vertebrata was the difficulty which made most impression on me on first reading the 'Genesis of Species,' I will allude to it more especially. 'In the cuttle fish,' says Mr. Mivart, 'we find an eye even more completely constructed on the vertebrate type than is the ear. Sclerotic, retina, choroid, vitreous humour, lens, aqueous humour, all are present. The correspondence is wonderfully complete, and there can hardly be any hesitation in saying that, for such an exact, prolonged, and correlated

series of similar structures to have been brought about in two independent instances by merely indefinite and minute accidental variations, is an improbability which amounts practically to impossibility.' Yet these organs in the two types must have been developed in entire and complete independence one of the other, for it would be impossible to find a common ancestor without going back to some very simple form not yet provided with even the rudiments of vision. To this Mr. Darwin replies,* that there is hardly any real resemblance between the eyes of the cuttle-fish and vertebrates—the retina in the cephalopod being totally different, with an actual inversion of the elemental parts, and with a large nervous ganglion included within the membranes of the eye. At the same time he allows that both are formed of transparent tissue and furnished with a lens for throwing an image into a darkened chamber: this, however, he contends is accounted for by the necessary conditions of the formation of any organ of vision, and he cites Hensen as having shown in a recent memoir on the Cephalopod that the fundamental structure in that type of animal is so distinct that it is not a little difficult to decide how far even the same terms ought to be employed in describing the analogous points of structure of the eyes of the cephalopoda and vertebrata.

For my own part, while allowing that Mr. Mivart may have overstated the resemblance or identity of the organs of the two classes, it still appears to me that the objections alluded to by me in the 10th edition,† when commenting on the arguments brought forward in the 'Reign of Law,' are strengthened by Mr. Darwin's admission that certain common conditions in the external world have caused the cephalopoda to acquire a transparent tissue, a lens, and a darkened chamber strictly analogous to those in the eye of the vertebrate without derivation by inheritance from a common ancestor. Some geologists, when speculating on the co-existence ‡ of vertebrates, insects, and cephalopods

* 'Origin of Species,' 6th ed., p. 151, (1872).

† See p. 496, present volume.

‡ Vol. I. chap. ix.; and 'Student's Elements,' p. 447.

in the Silurian strata, the oldest of which the fauna can be said to be extensively known to us, have dwelt on the small approach which we seem to have made in those ancient rocks to the beginning of organic life, assuming it to be necessary to suppose that there has been a regular gradation from the more simple to the most highly differentiated type. But the difficulty of so early a co-existence of the three types no longer exists when we admit that the highest parts of their organisation, which discharge the same functional duties in all three, have been independently superinduced by the action of outward conditions, and that we need not derive them by inheritance from some common starting-point.

Neither Mr. Mivart nor the Duke of Argyll, however, have by any means argued, like the majority of Mr. Darwin's opponents, as if nothing had been gained by the theory of Natural Selection, merely because this principle may have had functions assigned to it far higher than it can possibly discharge. The real question at issue—that on which the 'Origin of Species' has thrown so much light—is the same as that discussed by us in the last ten chapters. It is not whether we can explain the creation of species, but whether species have been introduced into the world one after the other, in the form of new varieties of antecedent organisms and in the way of ordinary generation, or have been called into being by some other agency, such as the direct intervention of the First Cause. Was Lamarck right, assuming progressive development to be true, in supposing that the changes of the organic world may have been effected by the gradual and insensible modification of older pre-existing forms? Mr. Darwin, without absolutely proving this, has made it appear in the highest degree probable, by an appeal to many distinct and independent classes of phenomena in natural history and geology, but principally by showing the manner in which a multitude of new and competing varieties are always made to survive in the struggle for life. The tenor of his reasoning is not to be gainsaid by affirming that the causes or processes which bring about the improvement or differentiation of organs, and the general advance of the

organic world from the simpler to the more complex, remain as inscrutable to us as ever.

When first the doctrine of the origin of species by transmutation was proposed, it was objected that such a theory substituted a material self-adjusting machinery for a Supreme Creative Intelligence. But the more the idea of a slow and insensible change from lower to higher organisms, brought about in the course of millions of generations according to a preconceived plan, has become familiar to men's minds, the more conscious they have become that the amount of power, wisdom, design, or forethought, required for such a gradual evolution of life, is as great as that which is implied by a multitude of separate, special, and miraculous acts of creation.

A more serious cause of disquiet and alarm arises out of the supposed bearing of this same doctrine on the origin of man and his place in nature. It is clearly seen that there is such a close affinity, such an identity in all essential points, in our corporeal structure and in many of our instincts and passions, with those of the lower animals—that man is so completely subjected to the same general laws of reproduction, increase, growth, disease, and death,—that if progressive development, spontaneous variation, and natural selection have for millions of years directed the changes of the rest of the organic world, we cannot expect to find that the human race has been exempted from the same continuous process of evolution. Such a near bond of connection between man and the rest of the animate creation is regarded by many as derogatory to our dignity. It certainly gives a rude shock to many traditional beliefs, and dispels some poetic illusions respecting an ideal genealogy which scarcely 'appeared less than archangel ruined.' But we have already had to exchange the pleasing conceptions indulged in by poets and theologians as to the high position in the scale of being held by our early progenitors, for more humble and lowly beginnings, the joint labours of the geologist and archæologist having left us in no doubt of the ignorance and barbarism of Paleolithic Man.*

* For remarks on Paleolithic Man see close of Chapter XLVII.

We are sometimes tempted to ask whether the time will ever arrive, when science shall have obtained such an ascendency in the education of the millions, that it will be possible to welcome new truths, instead of always looking upon them with fear and disquiet, and to hail every important victory gained over error, instead of resisting the new discovery, long after the evidence in its favour is conclusive. The motion of our planet round the sun, the shape of the earth, the existence of the antipodes, the vast antiquity of our globe, the distinct assemblages of species of animals and plants by which it was successively inhabited, and lastly the antiquity and barbarism of Primeval Man, all these generalisations, when first announced, have been a source of anxiety and unhappiness. The future now opening before us begins already to reveal new doctrines, if possible more than ever out of harmony with cherished associations of thought. It is therefore desirable, when we contrast ourselves with the rude and superstitious savages who preceded us, to remember, as cultivators of science, that the high comparative place which we have reached in the scale of being has been gained step by step by a conscientious study of natural phenomena, and by fearlessly teaching the doctrines to which they point. It is by faithfully weighing evidence, without regard to preconceived notions, by earnestly and patiently searching for what is true, not what we wish to be true, that we have attained that dignity, which we may in vain hope to claim through the rank of an ideal parentage.

CHAPTER XLIV.

ENCLOSING OF FOSSILS IN PEAT, BLOWN SAND, AND VOLCANIC EJECTIONS.

DIVISION OF THE SUBJECT—IMBEDDING OF ORGANIC REMAINS IN DEPOSITS ON EMERGED LAND—GROWTH OF PEAT—SITE OF ANCIENT FORESTS IN EUROPE NOW OCCUPIED BY PEAT—BOG IRON-ORE—PRESERVATION OF ANIMAL SUBSTANCES IN PEAT—MIRING OF QUADRUPEDS—BURSTING OF THE SOLWAY MOSS—IMBEDDING OF ORGANIC BODIES AND HUMAN REMAINS IN BLOWN SAND—GREAT DISMAL SWAMP—MOVING SANDS OF AFRICAN DESERTS—BURIED TEMPLE OF IPSAMBUL IN EGYPT—DRIED CARCASSES IN THE SANDS OF THE DESERT—SAND-DUNES AND TOWNS OVERWHELMED BY SAND-FLOODS—IMBEDDING OF ORGANIC AND OTHER REMAINS IN VOLCANIC FORMATIONS ON THE LAND.

The second branch of our enquiry, respecting changes of the organic world, relates to the processes by which the remains of animals and plants become fossil, or are buried in the earth by natural causes. M. Constant Prevost divided the effects of geological causes into two great classes: those produced during the submersion of land beneath the waters, and those which take place after its emersion. I shall consider, first, in what manner animal and vegetable remains become included and preserved in deposits on emerged land, or that part of the surface which is not *permanently* covered by water, whether of lakes or seas; secondly, the manner in which organic remains become imbedded in deposits of lakes and seas.

Under the first division, I shall treat of the following topics:—1st, the growth of peat, and the preservation of vegetable and animal remains therein; 2ndly, the burying of organic remains in blown sand; 3rdly, of the same in the ejections and alluviums of volcanos; 4thly, in alluviums generally, and in the ruins of landslips; 5thly, in the mud and stalagmite of caves and fissures.

Growth of peat, and preservation of vegetable and animal remains therein.—The generation of peat, when not completely under water, is confined to moist situations, where the temperature is low. It may consist of any of the numerous plants which are capable of growing in such *stations;* but a species of moss (*Sphagnum*) constitutes a considerable part of the peat found in marshes of the north of Europe; this plant having the property of throwing up new shoots in its upper part, while its lower extremities are decaying.* Reeds, rushes, and other aquatic plants may usually be traced in peat; and their organisation is often so entire that there is no difficulty in discriminating the distinct species.

In general, says Sir H. Davy, one hundred parts of dry peat contain from sixty to ninety-nine parts of matter destructible by fire; and the residuum consists of earths usually of the same kind as the substratum of clay, marl, gravel, or rock, on which they are found, together with oxide of iron. 'The peat of the chalk counties of England,' observes the same writer, 'contains much gypsum: but I have found very little in any specimens from Ireland or Scotland, and in general these peats contain very little saline matter.'† From the researches of Dr. MacCulloch, it appears that peat is intermediate between simple vegetable matter and lignite.‡

Peat is sometimes formed on a declivity in mountainous regions, where there is much moisture; but in such situations it rarely, if ever, exceeds four feet in thickness. In bogs, and in low grounds into which alluvial peat is drifted, it is found forty feet thick and upwards; but in such cases it generally owes one half of its volume to the water which it contains. It has seldom been discovered within the tropics, although Mr. Wallace informs me that there is often a great depth of soft peaty matter in the swampy forests of Borneo; and it rarely occurs in the valleys, even in the south of France and Spain. It abounds more and more, in proportion as we advance farther from the equator,

* For a catalogue of plants which form peat, see Rev. Dr. Rennie's Essays on Peat, p. 171; and Dr. MacCulloch's Western Isles, vol. i. p. 129.

† Irish Bog Reports, p. 209.

‡ System of Geology, vol. ii. p. 353.

and becomes not only more frequent but more inflammable in northern latitudes.*

The same phenomenon is repeated in the southern hemisphere. No peat is found in Brazil, nor even in the swampy parts of the country drained by the La Plata on the east side of South America, or in the island of Chiloe on the west; yet when we reach the 45th degree of latitude and examine the Chonos Archipelago or the Falkland Islands, and Tierra del Fuego, we meet with an abundant growth of this substance. Almost all plants contribute here by their decay to the production of peat, even the grasses; but it is a singular fact, says Mr. Darwin, as contrasted with what occurs in Europe, that no kind of moss enters into the composition of the South American peat, which is formed by many plants, but chiefly by that called by Brown *Astelia pumila*.†

I learnt from Dr. Forchhammer, in 1849, that water charged with vegetable matter in solution does not throw down a deposit of peat in countries where the mean temperature of the year is above 43° or 44° Fahrenheit. Frost causes the precipitation of such peaty matter, but in warm climates the attraction of the carbon for the oxygen of the air mechanically mixed with the water increases with the increasing temperature, and the dissolved vegetable matter or humic acid (which is organic matter in a progressive state of decomposition) being converted into carbonic acid, rises and is absorbed into the atmosphere, and thus disappears.

Extent of surface covered by peat.—There is a vast extent of surface in Europe covered with peat, which, in Ireland, is said to spread over a tenth of the whole island. One of the mosses on the Shannon is described as being fifty miles long, by two or three broad; and the great marsh of Montoire, near the mouth of the Loire, is mentioned by Blavier, as being more than fifty leagues in circumference. According to Rennie, many of these mosses of the north of Europe occupy the place of forests of pine and oak, which have,

* Rev. Dr. Rennie on Peat, p. 260.

† Darwin's Journal, p. 349; 2nd ed. p. 287.

many of them, disappeared within the historical era. Such changes are brought about by the fall of trees and the stagnation of water, caused by their trunks and branches obstructing the free drainage of the atmospheric waters, and giving rise to a marsh. In a warm climate, such decayed timber would immediately be removed by insects, or by putrefaction; but, in the cold temperature now prevailing in our latitudes, many examples are recorded of marshes produced in this manner. Thus, in Mar forest, in Aberdeenshire, large trunks of Scotch fir, which had fallen from age and decay, are said to have been soon immured in peat, formed partly out of their perishing leaves and branches, and in part from the growth of other plants. We are also told that the overthrow of a forest by a storm, about the middle of the seventeenth century, gave rise to a peat-moss near Lochbroom, in Ross-shire, and that, in less than half a century after the fall of the trees, the inhabitants dug peat there.* But the rate at which peat is known to form in places where its growth has been carefully noted by scientific observers, is so slow that it is necessary to receive these accounts with caution.

Nothing is more common than the occurrence of buried trees at the bottom of the Irish peat-mosses, as also in most of those of England, France, and Holland; and they have been so often observed with parts of their trunks standing erect, and with their roots fixed to the subsoil, that no doubt can be entertained of their having generally grown on the spot. They consist, for the most part, of the fir, the oak, and the birch: where the subsoil is clay, the remains of oak are the most abundant; where sand is the substratum, fir prevails. In the marsh of Curragh, in the Isle of Man, vast trees are discovered standing firm on their roots, though at the depth of eighteen or twenty feet below the surface. Some naturalists have desired to refer the imbedding of timber in peat-mosses to aqueous transportation, since rivers are well known to float wood into lakes; but the facts above mentioned show that, in numerous instances, such an hypothesis is inadmissible. It has, moreover, been observed,

* Rennie's Essays on Peat, p. 65.

that in Scotland, as also in many parts of the Continent, the largest trees are found in those peat-mosses which lie in low regions, and that the trees are proportionally smaller in those which lie at higher levels; from which fact De Luc and Walker have both inferred that the trees grew on the spot, for they would naturally attain a greater size in lower and warmer levels. The leaves, also, and fruits of each species, are continually found immersed in the moss along with the parent trees; as, for example, the leaves and acorns of the oak, the cones and leaves of the fir, and the nuts of the hazel.

Supposed recent origin of some peat-mosses.—In Hatfield Moss, in Yorkshire, which appears clearly to have been a forest eighteen hundred years ago, fir-trees have been found 90 feet long, and sold for masts and keels of ships; oaks have also been discovered there above 100 feet long. The dimensions of an oak from this moss are given in the Philosophical Transactions, No. 275, which must have been larger than any tree now existing in the British dominions.

In the same moss of Hatfield, as well as in that of Kincardine, in Scotland, and several others, Roman roads are said to have been found covered to the depth of eight feet by peat, and it has also been affirmed that all the coins, axes, arms, and other utensils found in British and French mosses, are Roman. But the more careful examinations made of late years of the deposits of peat about 30 feet thick at Amiens, Abbeville, and other places in the valley of the Somme, lead me to distrust the inferences formerly drawn as to the age of a large portion of the European peat, which has been supposed to be of later date than the time of Julius Cæsar. M. Boucher de Perthes ascertained that Gallo-Roman remains occur at Abbeville, in peat nearer the surface than the more ancient weapons called Celts of the Stone period. The same antiquary also remarked that the depth at which Roman works of art are met with, is not always a sure test of age, because in some parts of the swamp, especially near the river, the peat is often so fluid that heavy substances may sink through it.* Recent re-

* See 'Antiquity of Man,' p. 110.

searches may be said to have demonstrated that no small part of the European peat is pre-Roman and belongs to the age of bronze instruments, and even in great part to the antecedent Neolithic Stone period, of which more will be said in Chapter XLVII.

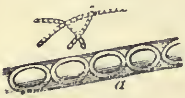
According to De Luc, the very sites of the aboriginal forests of Hercynia, Semana, Ardennes, and several others, are now occupied by mosses and fens. A great part of these changes have, with much probability, been attributed to the strict orders given by Severus, and other emperors, to destroy all the wood in the conquered provinces. So also many of the British forests, which are now mosses, were cut down at different periods, by order of the English parliament, because they harboured wolves or outlaws. Thus the Welsh woods were cut down and burnt, in the reign of Edward I.; as were many of those in Ireland, by Henry II., to prevent the natives from harbouring in them, and harassing his troops.

It is a remarkable fact, that in the Danish islands, and in Jutland as well as in Holstein, trunks of the Scotch fir, *Pinus sylvestris*, are found at the bottom of the peat-mosses, although this species of fir has not been a native of the same countries in historical times, and, when introduced there, has not thriven. Higher up in the Danish peat-mosses, prostrate trunks of the sessile variety of the common oak occur, while at a still higher level, the pedunculated variety of the same oak, *Quercus robur*, Linn., is met with, together with the alder, birch, and hazel. The oak has now in its turn been almost supplanted in Denmark by the common beech. There appears therefore to have been a natural rotation of trees in that country; one set of species, which lived on the borders of the swamps, having died out and another succeeded. These changes took place, all of them, before the historical era; but remains of man have been found even in the fundamental peat in which the Scotch firs lie buried, and a flint implement has been taken out, by Steenstrup himself, from below one of the buried pines. It was a weapon of the later Stone period or Neolithic age—no remains of Paleolithic Man having yet been discovered in any part of Scandinavia.*

* Lubbock, Introduction to Nilsson on the Stone Age, 1868.

Sources of bog iron-ore.—At the bottom of peat-mosses there is sometimes found a cake, or 'pan,' as it is termed, of oxide of iron, and the frequency of bog iron-ore is familiar to the mineralogist. The oak, which is so often dyed black in peat, owes its colour to the same metal. From what source the iron is derived has often been a subject of discussion, until the discoveries of Ehrenberg seem at length to have removed the difficulty. He had observed, in the marshes about Berlin, a substance of a deep ochre yellow passing into red, which covered the bottom of the ditches, and which, where it had become dry after the evaporation of the water, appeared exactly like oxide of iron. But under the microscope it was found to consist of slender articulated threads or plates, partly siliceous and partly ferruginous, of a plant of simple structure, *Gallionella ferruginea*, of the family called Diatomaceæ.* There can be little doubt, therefore, that bog iron-ore consists of an aggregate of millions of these organic bodies invisible to the naked eye.†

Fig. 145.



Gallionella ferruginea.
a. 2000 times magnified.

Preservation of animal substances in peat.—One interesting circumstance attending the history of peat-mosses is the high state of preservation of animal substances buried in them for periods of many years. In June, 1747, the body of a woman was found six feet deep, in a peat-moss in the Isle of Axholm, in Lincolnshire. The antique sandals on her feet afforded evidence of her having been buried there for many centuries; yet her nails, hair, and skin are described as having shown hardly any marks of decay. On the estate of the Earl of Moira, in the north of Ireland, a human body was dug up, a foot deep in gravel, covered with eleven feet of peat; the body was completely clothed, and the garments seemed all to be made of hair. Before the use of wool was known in that country the clothing of the inhabitants was made of hair, so that it would appear that this body had been buried at that early period; yet it was fresh and

* See above, vol. i. p. 645.

† Ehrenberg, Taylor's Scientific Mem., vol. i. part iii. p. 402.

unimpaired.* In the Philosophical Transactions we find an example recorded of the bodies of two persons having been buried in moist peat, in Derbyshire, in 1674, about a yard deep, which were examined twenty-eight years and nine months afterwards; 'the colour of their skin was fair and natural, their flesh soft as that of persons newly dead.' †

Among other analogous facts we may mention, that in digging a pit for a well near Dulverton, in Somersetshire, many pigs were found in various postures, still entire. Their shape was well preserved, the skin, which retained the hair, having assumed a dry, membranous appearance. Their flesh was converted into a white, friable, laminated, inodorous, and tasteless substance; but which, when exposed to heat, emitted an odour precisely similar to that of broiled bacon.‡

We naturally ask whence peat derives this antiseptic property? It has been attributed by some to the carbonic and gallic acids which issue from decayed wood, as also to the presence of charred wood in the lowest strata of many peat-mosses, for charcoal is a powerful antiseptic, and capable of purifying water already putrid. Vegetable gums and resins also may operate in the same way.§

The tannin occasionally present in peat is the produce, says Dr. MacCulloch, of tormentilla, and some other plants; but the quantity he thinks too small, and its occurrence too casual, to give rise to effects of any importance. He hints that the soft parts of animal bodies, preserved in peat-bogs, may have been converted into adipocere by the action of water only.‖

Miring of quadrupeds.—The manner, however, in which peat contributes to preserve, for indefinite periods, the harder parts of terrestrial animals, is a subject of more immediate interest to the geologist. There are two ways in which animals become occasionally buried in the peat of marshy grounds; they either sink down into the semifluid mud,

* Dr. Rennie on Peat, p. 521; where several other instances are referred to.

† Phil. Trans. vol. xxxviii. 1734.

‡ Dr. Rennie on Peat, &c., p. 521.

§ Ibid. p. 531.

‖ Syst. of Geol. vol. ii. pp. 340—346.

underlying a turfy surface upon which they have rashly ventured, or, at other times, as we shall see in the sequel, a bog 'bursts,' and animals may be involved in the peaty alluvium.

In the extensive bogs of Newfoundland, cattle are sometimes found buried alive with only their heads and necks above ground; and after having remained for days in this situation, they have been drawn out by ropes and saved. In Scotland, also, cattle venturing on a 'quaking moss,' are often mired, or 'laired,' as it is termed; and in Ireland, Mr. King asserts that the number of cattle which are lost in sloughs is quite incredible.*

Solway Moss.—The description given of the Solway Moss will serve to illustrate the general character of these boggy grounds. That moss, observes Gilpin, is a flat area, about seven miles in circumference, situated on the western confines of England and Scotland. Its surface is covered with grass and rushes, presenting a dry crust and a fair appearance; but it shakes under the least pressure, the bottom being unsound and semifluid. The adventurous passenger, therefore, who sometimes in dry seasons traverses this perilous waste, to save a few miles, picks his cautious way over the rushy tussocks as they appear before him, for here the soil is firmest. If his foot slip, or if he venture to desert this mark of security, it is possible he may never more be heard of.

'At the battle of Solway, in the time of Henry VIII. (1542), when the Scotch army, commanded by Oliver Sinclair, was routed, an unfortunate troop of horse, driven by their fears, plunged into this morass, which instantly closed upon them. The tale was traditional, but it is now so far authenticated, that a man and a horse, in complete armour, have been found by peat-diggers, in the place where it was always supposed the affair had happened. The skeleton of each was well preserved, and the different parts of the armour easily distinguished.' †

The same moss, on the 16th of December, 1772, having

* Phil. Trans. vol. xv. p. 949.

† Gilpin, Observ. on Picturesque Beauty, &c., 1772.

been filled like a great sponge with water during heavy rains, swelled to an unusual height above the surrounding country, and then burst. The turfy covering seemed for a time to act like the skin of a bladder retaining the fluid within, till it forced a passage for itself, when a stream of black half-consolidated mud began at first to creep over the plain, resembling in the rate of its progress an ordinary lava-current. No lives were lost, but the deluge totally overwhelmed some cottages, and covered 400 acres. The highest parts of the original moss subsided to the depth of about 25 feet; and the height of the moss, on the lowest parts of the country which it invaded, was at least 15 feet.

Bursting of peat-mosses.—An inundation in Sligo in January, 1831, affords another example of this phenomenon. After a sudden thaw of snow, the bog between Bloomfield and Geevah gave way; and a black deluge, carrying with it the contents of a hundred acres of bog, took the direction of a small stream and rolled on with the violence of a torrent, sweeping along heath, timber, mud, and stones, and overwhelming many meadows and much arable land. On passing through some boggy land, the flood swept out a wide and deep ravine, and part of the road leading from Bloomfield to St. James's Well was completely carried away from below the foundation for the breadth of 200 yards.

An ancient log-cabin is recorded as having been found in 1833 at the depth of fourteen feet in the peat of Donegal. The cabin was filled with peat and was surrounded by other huts, which were not examined. The trunks and roots of trees preserved in their natural position surrounded these huts. There can be little doubt that we have here an example of a village which at some unknown period was overwhelmed by the bursting of a moss. In such cases the depth of vegetable matter which may overlie the dwelling affords no test of antiquity, as the whole thickness may have accumulated at once when the catastrophe occurred.

From the facts before mentioned, respecting the bursting of mosses and the manner in which they frequently descend in a fluid state to lower levels, the reader will readily perceive that lakes and arms of the sea must occasionally become the

receptacles of drift peat. Of this, accordingly, there are numerous examples; and hence the alternations of clay and sand with different deposits of peat so frequent on some coasts, as on those of the Baltic and German Ocean. We are informed by Deguer, that remains of ships, nautical instruments, and oars, have been found in many of the Dutch mosses. Gerard has shown by similar proofs that many mosses on the coast of Picardy, Zealand, and Friesland were at one period navigable arms of the sea.

Bones of herbivorous quadrupeds in peat.—The antlers of large and full-grown stags are amongst the most common and conspicuous remains of animals in peat. They are not horns which have been shed; for portions of the skull are found attached, proving that the whole animal perished. Bones of the ox, hog, horse, sheep, and other herbivorous animals, also occur. M. Morren discovered in the peat of Flanders the bones of otters and beavers,* and M. Boucher de Perthes found bones and teeth of the *Ursus arctos*, or the bear which now lives in the Pyrenees, in the peat of Abbeville. But as a general rule no remains are met with belonging to extinct quadrupeds, such as the elephant, rhinoceros, hippopotamus, hyæna, and tiger, which are so common in old European river-gravels.

Bones of the mammoth mentioned by us in the first volume, pp. 549, 550, as occurring in peat and vegetable matter of older date than ordinary peat-mosses, are very exceptional. The great extinct deer also, *Cervus megaceros*, has often been said to have been dug out of peat, but its true position seems to be in shell-marl underlying peat-mosses. The freshwater shells of such marl and others occasionally associated with peat, as well as the landshells met with in the same, are invariably of species now living.

Great Dismal Swamp.—I have described in my 'Travels in North America,'† an extensive swamp or morass, 40 miles long from north to south, and 25 wide, between the towns of Norfolk in Virginia, and Weldon in North Carolina. It is called the 'Great Dismal,' and has somewhat the

* Bulletin de la Soc. Géol. de France, tom. ii. p. 26.

† Travels, &c., in 1841, 1842, vol. i. p. 143.

appearance of an inundated river-plain covered with aquatic trees and shrubs, the soil being as black as that of a peat-bog. It is higher on all sides except one than the surrounding country, towards which it sends forth streams of water to the north, east, and south, receiving a supply from the west only. In its centre it rises 12 feet above the flat region which bounds it. The soil, to the depth of 15 feet, is formed of vegetable matter without any admixture of earthy particles, and offers an exception to a general rule before alluded to, namely, that such peaty accumulations scarcely ever occur so far south as lat. 36°, or in any region where the summer heat is so great as in Virginia. In digging canals through the morass for the purpose of obtaining timber much of the black soil has been thrown out from time to time, and exposed to the sun and air, in which case it soon rots away, so that nothing remains behind, showing clearly that it owes its preservation to the shade afforded by a luxuriant vegetation and to the constant evaporation of the spongy soil by which the air is cooled during the hot months. The surface of the bog is carpeted with mosses, and densely covered with ferns and reeds, above which many evergreen shrubs and trees flourish, especially the White Cedar (*Cupressus thyoides*), which stands firmly supported by its long tap roots in the softest parts of the quagmire. Over the whole the deciduous Cypress (*Taxodium distichum*) is seen to tower with its spreading top, in full leaf in the season when the sun's rays are hottest, and when, if not intercepted by a screen of foliage, they might soon cause the fallen leaves and dead plants of the preceding autumn to decompose, instead of adding their contributions to the peaty mass. On the surface of the whole morass lie innumerable trunks of large and tall trees blown down by the winds, while thousands of others are buried at various depths in the black mire below. They remind the geologist of the prostrate position of large stems of Sigillaria and Lepidodendron, converted into coal in ancient carboniferous rocks.

IMBEDDING OF HUMAN AND OTHER REMAINS, AND WORKS OF ART, IN BLOWN SAND.

The drifting of sand may next be considered among the causes capable of preserving organic remains and works of art on the emerged land.

African sands.—The sands of the African deserts have been driven by the west winds over part of the arable land of Egypt, on the western bank of the Nile, in those places where valleys open into the plain, or where there are gorges through the Libyan mountains. By similar sand-drifts the ruins of ancient cities have been buried between the temple of Jupiter Ammon and Nubia.

We have seen that Sir J. G. Wilkinson is of opinion that, while the sand-drift is making aggressions at certain points upon the fertile soil of Egypt, the alluvial deposit of the Nile is advancing very generally upon the desert; and that, upon the whole, the balance is greatly in favour of the fertilising mud. *

No mode of interment can be conceived more favourable to the conservation of monuments for indefinite periods than that now so common in the region immediately westward of the plain of the Nile. The sand which surrounded and filled the great temple of Ipsambul, first discovered by Burckhardt, and afterwards partially uncovered by Belzoni and Beechey, was so fine as to resemble a fluid when put in motion. Neither the features of the colossal figures, nor the colour of the stucco with which some were covered, nor the paintings on the walls, had received any injury from being enveloped for ages in this dry impalpable dust.†

At some future period, perhaps when the Pyramids shall have perished, changes in the surrounding sea and land may modify the climate and the direction of the prevailing winds, so that these may then waft away the Libyan sands as gradually as they once brought them to those regions, and may lay open to the day some of these buried temples.

* See vol. i. p. 430.

† Stratton, Ed. Phil. Journ., No. v. p. 62.

Whole caravans are said to have been overwhelmed by the Libyan sands; and Burckhardt informs us that 'after passing the Akaba near the head of the Red Sea, the bones of dead camels are the only guides of the pilgrim through the wastes of sands.'—'We did not see,' says Captain Lyon, speaking of a plain near the Soudah mountains, in Northern Africa, 'the least appearance of vegetation; but observed many skeletons of animals, which had died of fatigue on the desert, and occasionally the grave of some human being. All these bodies were so dried by the heat of the sun, that putrefaction appears not to have taken place after death. In recently expired animals I could not perceive the slightest offensive smell; and in those long dead, the skin with the hair on it remained unbroken and perfect, although so brittle as to break with a slight blow. The sand-winds never cause these carcasses to change their places; for, in a short time, a slight mound is formed round them, and they become stationary.'*

Towns overwhelmed by sand-floods.—The burying of several towns and villages in England, France, and Jutland, by blown sand is on record; thus, for example, near St. Pol de Leon, in Brittany, a whole village was completely buried beneath drift-sand, so that nothing was seen but the spire of the church.† In Jutland marine shells adhering to seaweed are sometimes blown by the violence of the wind to the height of 100 feet and buried in similar hills of sand.

In Suffolk, in the year 1688, part of Downham was overwhelmed by sands which had broken loose about 100 years before, from a warren five miles to the south-west. This sand had, in the course of a century, travelled four miles, and covered more than 1,000 acres of land.‡ A considerable tract of cultivated land on the north coast of Cornwall has been inundated by drift sand, forming hills several hundred feet above the level of the sea, and composed of comminuted marine shells, in which some terrestrial shells are enclosed entire. By the shifting of these sands the ruins of ancient

* Travels in North Africa in the Years 1818, 1819, and 1820, p. 83.

† Mém. de l'Acad. des Sci. de Paris, 1772. See also the case of the buried church of Eccles, vol. i. p. 518.

‡ Phil. Trans. vol. iii. p. 722.

buildings have been discovered, among which is the church of St. Piran, in the parish of Perranzabuloe, or Perran in Sabulo, which I saw half exposed in 1870; and in some cases where wells have been bored to a great depth, distinct strata, separated by a vegetable crust, are visible. In some places, as at New Quay, large masses have become sufficiently indurated to be used for architectural purposes. The lapidification which is still in progress, appears to be due to oxide of iron held in solution by the water which percolates the sand.*

IMBEDDING OF ORGANIC AND OTHER REMAINS IN VOLCANIC FORMATIONS ON THE LAND.

I have in some degree anticipated the subject of this section in former chapters, when speaking of the buried cities around Naples, and those on the flanks of Etna.† From the facts referred to, it appeared that the preservation of human remains and works of art is frequently due to the descent of floods caused by the copious rains which accompany eruptions. These aqueous lavas, as they are called in Campania, flow with great rapidity; and in 1822 surprised and suffocated seven persons in the villages of St. Sebastian and Massa, on the flanks of Vesuvius.

In the tuffs, moreover, or solidified mud, deposited by these aqueous lavas, impressions of leaves and of trees have been observed. Some of those, formed after the eruption of Vesuvius in 1822, are now preserved in the Museum at Naples.

Lava itself may become indirectly the means of preserving terrestrial remains, by overflowing beds of ashes, pumice, and ejected matter, which may have been showered down upon animals and plants, or upon human remains. Few substances are better non-conductors of heat than volcanic dust and scoriæ, so that a bed of such materials is rarely melted by a superimposed lava current. After consolidation, the lava affords secure protection to the lighter and more removable

* Boase on Submersion of Part of the Mount's Bay, &c., Trans. Roy. Geol. Soc. of Cornwall, vol. ii. p. 140.

† Vol. i. p. 641, and vol. ii. p. 22.

mass below, in which the organic relics may be enveloped. The Herculanean tuffs containing the rolls of papyrus, of which the characters are still legible, have, as was before remarked, been for ages covered by lava.

Another mode by which lava may tend to the preservation of imbedded remains, at least of works of human art, is by its overflowing them when it is not intensely heated, in which case they sometimes suffer little or no injury.

Thus when the Etnean lava-current of 1669 covered fourteen towns and villages, and part of the city of Catania, it did not melt down coins and other articles in the vaults of Catania; and at the depth of 35 feet under the same current, on the site of Monpilere, one of the buried towns, the bell of a church and some statues were found uninjured (p. 24).

CHAPTER XLV.

BURYING OF FOSSILS IN ALLUVIAL DEPOSITS AND IN CAVES.

FOSSILS IN ALLUVIUM—EFFECTS OF SUDDEN INUNDATIONS—TERRESTRIAL ANIMALS MOST ABUNDANTLY PRESERVED IN ALLUVIUM WHERE EARTHQUAKES PREVAIL—MARINE ALLUVIUM—BURIED TOWNS—EFFECTS OF LANDSLIPS—ORGANIC REMAINS IN FISSURES AND CAVES—FORM AND DIMENSIONS OF CAVERNS—THEIR PROBABLE ORIGIN—CLOSED BASINS AND SUBTERRANEAN RIVERS OF THE MOREA—KATAVOTHRA—FORMATION OF BRECCIAS WITH RED CEMENT—HUMAN REMAINS IMBEDDED IN MOREA—SCHMERLING ON INTERMIXTURE OF HUMAN REMAINS AND BONES OF EXTINCT QUADRUPEDS AS PROVING THE FORMER CO-EXISTENCE OF MAN WITH THOSE LOST SPECIES—BONE-BRECCIAS FORMED IN OPEN FISSURES AND CAVES.

Fossils in Alluvium.—The next subject for our consideration, according to the division before proposed, is the imbedding of organic bodies in alluvium.

The gravel, sand, and mud in the bed of a river do not often contain any animal or vegetable remains; for the whole mass is so continually shifting its place, and the attrition of the various parts is so great, that even the hardest rocks contained in it are, at length, ground down to powder. But when sand and sediment are swept by a flood over lands bordering a river, such an alluvium may envelop trees or the remains of animals, which, in this manner, are often permanently preserved. In the mud and sand produced by the floods in Scotland, in 1829, the dead and mutilated bodies of hares, rabbits, moles, mice, partridges, and even the bodies of men, were found partially buried.* But in these and similar cases one flood usually effaces the memorials left by another, and it is only when rivers are eroding and deepening valleys that portions of old river channels are left high and dry beyond the reach of floods, in which case the organic remains may be preserved for ages.

* Sir T. D. Lauder, Bart., on Floods in Morayshire, Aug. 1829, p. 177.

In districts repeatedly deranged by earthquakes, rivers often shift their channels from one part of a valley to another, and alluvial accumulations caused by transient floods become permanent depositaries of organic substances.

Marine alluvium.—In May, 1787, a dreadful inundation of the sea was caused at Coringa, Ingeram, and other places, on the coast of Coromandel, in the East Indies, by a hurricane blowing from the N.E., which raised the waters so that they rolled inland to the distance of about twenty miles from the shore, swept away many villages, drowned more than 10,000 people, and left the country covered with marine mud, on which the carcasses of about 100,000 head of cattle were strewed. An old tradition of the natives of a similar flood, said to have happened about a century before, was, till this event, regarded as fabulous by the European settlers.* The same coast of Coromandel was, so late as May, 1832, the scene of another catastrophe of the same kind; and when the inundation subsided, several vessels were seen grounded in the fields of the low country about Coringa.

Many of the storms termed hurricanes have evidently been connected with submarine earthquakes, as shown by the atmospheric phenomena attendant on them, and by the sounds heard in the ground and the odours emitted.

Houses and works of art in alluvial deposits.—A very ancient subterranean town, apparently of Hindoo origin, was discovered in India in 1833, in digging the Doab Canal. Its site is north of Saharunpore, near the town of Behat, and 17 feet below the present surface of the country. More than 170 coins of silver and copper were found, and many articles in metal and earthenware. The overlying deposit consisted of about 5 feet of river sand, with a substratum, about 12 feet thick, of red alluvial clay. In the neighbourhood are several rivers and torrents, which descend from the mountains charged with vast quantities of mud, sand, and shingle; and within the memory of persons now living the modern Behat has been threatened by an inundation, which, after retreating, left the neighbouring

* Dodsley's Ann. Regist., 1788.

country strewed over with a superficial covering of sand several feet thick. In sinking wells in the environs, masses of shingle and boulders have been reached resembling those now in the river-channels of the same district, under a deposit of thirty feet of reddish loam. Captain Cautley, therefore, who directed the excavations, supposes that the matter discharged by torrents has gradually raised the whole country skirting the base of the lower hills; and that the ancient town, having been originally built in a hollow, was submerged by floods, and covered over with sediment seventee nfeet in thickness.*

We are informed by M. Boblaye, that in the Morea, the formation termed céramique, consisting of pottery, tiles, and bricks, intermixed with various works of art, enters so largely into the alluvium and vegetable soil upon the plains of Greece, and into hard and crystalline breccias which have been formed at the foot of declivities, that it constitutes an important stratum, which might, even in the absence of zoological characters, serve to mark part of the human epoch in a most indestructible manner.†

Landslips.—The landslip, by suddenly precipitating large masses of rock and soil into a valley, sometimes buries permanently whole villages, with their inhabitants, and large herds of cattle and other animals. Thus three villages, with their entire population, were covered, when the mountain of Piz fell in 1772, in the district of Treviso, in the state of Venice,‡ and part of Mount Grenier, south of Chambery, in Savoy, which fell down in the year 1248, buried five parishes, including the town and church of St. André, the ruins occupying an extent of about nine square miles.§

The number of lives lost by the slide of the Rossberg, in Switzerland, in 1806, was estimated at more than 800, a great number of the bodies, as well as several villages and scattered houses, being buried deep under mud and rock. In the same country, several hundred cottages, with eighteen of their

* Journ. of Asiat. Soc., Nos. xxv. and xxix., 1834.

† Ann. des Sci. Nat., tom. xxii. p. 117, Feb. 1831.

‡ Malte-Brun's Geog., vol. i. p. 435.

§ Bakewell, Travels in the Tarentaise, vol. i. p. 201.

inhabitants and a great number of cows, goats, and sheep, were victims to the sudden fall of a bed of stones, thirty yards deep, which descended from the summits of the Diablerets in the Valais. In the year 1618, a portion of Mount Conto fell, in the district of Chiavenna, in Switzerland, and buried the town of Pleurs, with all its inhabitants, to the number of 2,430.

It is unnecessary to multiply examples of similar local catastrophes, which have been very numerous in mountainous parts of Europe, within the historical period, more especially in regions convulsed by earthquakes. It is where these occur that enormous masses of rock and earth, even in comparatively low and level countries, are detached from the sides of valleys, and cast down into the river courses, and often so unexpectedly that they overwhelm, even in the daytime, every living thing upon the plains.

PRESERVATION OF ORGANIC REMAINS IN FISSURES AND CAVES.

In the history of earthquakes it was shown that many hundreds of new fissures and chasms had opened in certain regions during the last 150 years, some of which are described as being of unfathomable depth. We also perceive that mountain masses have been violently fractured and dislocated, during their rise above the level of the sea; and thus we may account for the existence of many cavities in the interior of the earth by the simple agency of earthquakes; but there are some caverns, especially in limestone rocks, which, although usually, if not always, connected with rents, are nevertheless of such forms and dimensions, alternately expanding into spacious chambers, and then contracting again into narrow passages, that we cannot suppose them to have owed their origin exclusively to the mere fracturing and displacement of solid masses.

In the limestone of Kentucky, in the basin of Green River, one of the tributaries of the Ohio, a line of underground cavities has been traced in one direction for a distance of ten miles, without finding any termination; and one of the chambers, of which there are many, all connected by narrow

tunnels, is no less than ten acres in area, and 150 feet in its greatest height. Besides the principal series 'of antres vast,' there are a great many lateral embranchments not yet explored.*

The cavernous structure here alluded to is not altogether confined to calcareous rocks; for it has lately been observed in micaceous and argillaceous schist in the Grecian island of Thermia (Cythnos of the ancients), one of the Cyclades. Here also spacious halls, with rounded and irregular walls, are connected together by narrow passages or tunnels, and there are many lateral branches which have no outlet. A current of water has evidently at some period flowed through the whole, and left a muddy deposit of bluish clay upon the floor; but the erosive action of the stream cannot be supposed to have given rise to the excavations in the first instance. M. Virlet suggests that fissures were first caused by earthquakes, and that these fissures became the chimneys or vents for the disengagement of gas, generated below by volcanic heat. Gases, he observes, such as the muriatic, sulphuric, fluoric, and others, might, if raised to a high temperature, alter and decompose the rocks which they traverse. There are signs of the former action of such vapours in rents of the micaceous schist of Thermia, and thermal springs now issue from the grottos of that island. We may suppose that afterwards the elements of the decomposed rocks were gradually removed in a state of solution by mineral waters; a theory which, according to M. Virlet, is confirmed by the effect of heated gases which escape from rents in the isthmus of Corinth, and which have greatly altered and corroded the hard siliceous and jaspideous rocks.†

When we reflect on the quantity of carbonate of lime annually poured out by mineral waters, we are prepared to admit that large cavities must, in the course of ages, be formed at considerable depths below the surface in calcareous rocks.‡ These rocks, it will be remembered, are at once more soluble, more permeable, and more fragile, than any others,

* Nahum Ward, Trans. of Antiq. Soc. of Massachusetts. Holmes's United States, p. 438.

† Bull. de la Soc. Géol. de France, tom. ii. p. 329.

‡ See above, vol. i. p. 402.

at least all the compact varieties are very easily broken by the movements of earthquakes, which would produce only flexures in argillaceous strata. Fissures once formed in limestone are not liable, as in many other formations, to become closed up by impervious clayey matter, and hence a stream of acidulous water might for ages obtain a free and unobstructed passage.*

Morea.—Nothing is more common in limestone districts than the engulfment of rivers, which after holding a subterranean course of many miles escape again by some new outlet. As they are usually charged with fine sediment, and often with sand and pebbles where they enter, whereas they are commonly pure and limpid where they flow out again, they must deposit much matter in empty spaces in the interior of the earth. In addition to the materials thus introduced, stalagmite, or carbonate of lime, drops from the roofs of caverns, and in such mixture the bones of animals washed in by rivers are often entombed. In this manner we may account for those bony breccias which we often find in caves, some of which are of high antiquity, while others are very recent and in daily progress. It is necessary to the formation of stalagmite that only so much water should be present as suffices to hold the carbonate of lime in solution. No deposit therefore takes place if a stream be continuously flowing through the cavern, and even if a coating be deposited during a season of drought this may easily be broken up again if changes in the underground drainage of the country or a rainy winter cause the cavern to be again flooded. For this reason we find broken-up stalagmite occurring among the deposits of most caves, as in Kent's Hole and others. In no district are engulfed streams more conspicuous than in the Morea, where the phenomena attending them have been studied and described in great detail by M. Boblaye and his fellow-labourers of the French expedition to Greece.† Their account is peculiarly interesting to geologists, because it throws light on the red osseous breccias containing the bones of extinct quadrupeds which are so common in almost all the

* See remarks by M. Boblaye, Ann. des Mines, 3me série, tom. iv.

† Ann. des Mines, 3me série, tom. iv. 1833.

countries bordering the Mediterranean. It appears that the numerous caverns of the Morea occur in a compact limestone, of the age of the English chalk, immediately below which are arenaceous strata referred to the period of our greensand. In the more elevated districts of that peninsula there are many deep land-locked valleys, or basins, closed round on all sides by mountains of fissured and cavernous limestone. The year is divided almost as distinctly as between the tropics into a rainy season, which lasts upwards of four months, and a season of drought of nearly eight months' duration. When the torrents are swollen by the rains, they rush from surrounding heights into the enclosed basins; but, instead of giving rise to lakes, as would be the case in most other countries, they are received into gulfs or chasms, called by the Greeks 'Katavothra,' and which correspond to what are termed in England sink-holes or 'swallow-holes' in the chalk and limestone districts. The water of these torrents is charged with pebbles and red ochreous earth, resembling precisely the well-known cement of the osseous breccias of the Mediterranean. This deposit dissolves in acids with effervescence, and leaves a residue of hydrated oxide of iron, granular iron, impalpable grains of silex, and small crystals of quartz. Soil of the same description abounds everywhere on the surface of the decomposing limestone in Greece, that rock containing in it much siliceous and ferruginous matter.

Many of the Katavothra being insufficient to give passage to all the water in the rainy season, a temporary lake is formed round the mouth of the chasm, which then becomes still further obstructed by pebbles, sand, and red mud, thrown down from the turbid waters. The lake being thus raised, its waters generally escape through other openings, at higher levels, around the borders of the plain, constituting the bottom of the closed basin.

In some places, as at Kavaros and Tripolitza, where the principal discharge is by a gulf in the middle of the plain, nothing can be seen over the opening in summer, when the lake dries up, but a deposit of red mud, cracked in all directions. But the Katavothron is more commonly situated at the foot of the surrounding escarpment of limestone;

and in that case there is sometimes room enough to allow a person to enter, in summer, and even to penetrate far into the interior. Within is seen a suite of chambers, communicating with each other by narrow passages; and M. Virlet relates, that in one instance he observed, near the entrance, human bones imbedded in recent red mud, mingled with the remains of plants and animals of species now inhabiting the Morea. It is not wonderful, he says, that the bones of man should be met with in such receptacles; for so murderous have been the late wars in Greece, that skeletons are often seen lying exposed on the surface of the country.*

In summer, when no water is flowing into the Katavothron, its mouth, half closed up with red mud, is masked by a vigorous vegetation, which is cherished by the moisture of the place. It is then the favourite hiding-place and den of foxes and jackals; so that the same cavity serves at one season of the year for the habitation of carnivorous beasts, and at another as the channel of an engulfed river. Near the mouth of one chasm, M. Boblaye and his companions saw the carcass of a horse, in part devoured, the size of which seemed to have prevented the jackals from dragging it in: the marks of their teeth were observed on the bones, and it was evident that the floods of the ensuing winter would wash in whatsoever might remain of the skeleton.

It has been stated that the waters of all these torrents of the Morea are turbid where they are engulfed; but when they come out again, often at the distance of many leagues, they are perfectly clear and limpid, being only charged occasionally with a slight quantity of calcareous sand. The points of efflux are usually near the sea-shores of the Morea, but sometimes they are submarine; and when this is the case, the sands are seen to boil up for a considerable space, and the surface of the sea, in calm weather, swells in large convex waves. It is curious to reflect, that when this discharge fails in seasons of drought, the pressure of the sea may force its salt waters into subterraneous caverns, and carry in marine sand and shells, to be mingled with ossiferous mud, and the remains of terrestrial animals.

* Bull. de la Soc. Géol. de France, tom. iii. p. 223.

In general, however, the efflux of water at these inferior openings is constant and surprisingly uniform, seeming to prove that the caverns in the interior serve as reservoirs, and that the water escapes gradually from them, in consequence of the smallness of the rents and passages by which they communicate with the surface.

The phenomena above described are not confined to the Morea, but occur in Greece generally, and in those parts of Italy, Spain, Asia Minor, and Syria, where the calcareous formations of the Morea extend. The Copaic lake in Bœotia has no outlet, except by underground channels; and hence we can explain those traditional and historical accounts of its having gained on the surrounding plains and overflowed towns, as such floods must have happened whenever the outlet was partially choked up by mud, gravel, or the subsidence of rocks, caused by earthquakes. When speaking of the numerous fissures in the limestones of Greece, M. Boblaye reminds us of the famous earthquake of 469 B.C., when, as we learn from Cicero, Plutarch, Strabo, and Pliny, Sparta was laid in ruins, part of the summit of Mount Taygetus torn off, and numerous gulfs and fissures caused in the rocks of Laconia.

During the great earthquake of 1693, in Sicily, several thousand people were at once entombed in the ruins of caverns in limestone, at Sortino Vecchio; and, at the same time, a large stream, which had issued for ages from one of the grottos below that town, changed suddenly its subterranean course, and came out from the mouth of a cave lower down the valley, where no water had previously flowed. To this new point the ancient water-mills were transferred; as I learnt when I visited the spot in 1829.

When the courses of engulfed rivers are thus liable to change, from time to time, by alterations in the levels of a country, and by the rending and shattering of mountain masses, we must suppose that the dens of wild beasts will sometimes be inundated by subterranean floods, and their carcasses buried under heaps of alluvium. The bones, moreover, of individuals which have died in the recesses of caves, or of animals which have been carried in for prey, may be

drifted along, and mixed up with mud, sand, and fragments of rocks, so as to form osseous breccias.

In 1833 I had an opportunity of examining the celebrated caves of Franconia, and among others that of Rabenstein, then newly discovered. Their general form, and the nature and arrangement of their contents, appeared to me to agree perfectly with the notion of their having once served as the channels of subterranean rivers. This mode of accounting for the introduction of transported matter into the Franconian and other caves, filled up as they often are even to their roofs with osseous breccia, was long ago proposed by M. C. Prevost,* and seems at length to be very generally adopted. But I do not doubt that bears inhabited some of the German caves, or that the cavern of Kirkdale, in Yorkshire, was once the den of hyænas. The abundance of bony dung, associated with hyænas' bones, has been pointed out by Dr. Buckland, and with reason, as confirmatory of this opinion.

The same author observed in every cave examined by him in Germany, that deposits of mud and sand, with or without rolled pebbles and angular fragments of rock, were covered over with a *single* crust of stalagmite.† In the English caves he remarked a similar absence of *alternations* of alluvium and stalagmite. But Dr. Schmerling has discovered in a cavern at Chockier, about two leagues from Liége, three distinct beds of stalagmite, and between each of them a mass of breccia, and mud mixed with quartz pebbles, and in the three deposits the bones of extinct quadrupeds.‡

This exception does not invalidate the generality of the phenomenon pointed out by Dr. Buckland, one cause of which may perhaps be this, that if several floods pass at different intervals of time through a subterranean passage, the last, if it has power to drift along fragments of rock, will also tear up any alternating stalagmitic and alluvial beds that may have been previously formed. Another cause may be, that a particular line of caverns will rarely be so

* Mém. de la Soc. d'Hist. Nat. de Paris, tom. iv.

† Reliquiæ Diluvianæ, p. 108.

‡ Journ. de Géol., tom. i. p. 286. July, 1830.

situated, in relation to the lowest levels of a country, as to become, at two distinct epochs, the receptacle of engulfed rivers.

As the same chasms may remain open throughout periods of indefinite duration, the species inhabiting a country may in the meantime be greatly changed, and thus the remains of animals belonging to very different epochs may become mingled together in a common tomb.

In several caverns on the banks of the Meuse, near Liége, Dr. Schmerling found human bones in the same mud and breccia with those of the elephant, rhinoceros, bear, and other quadrupeds of extinct species. He has observed none of the dung of any of these animals; and from this circumstance, and the appearance of the mud and pebbles, he concludes that these caverns were never inhabited by wild beasts, but that their remains were washed in by a current of water. As the human skulls and bones were in fragments, and no entire skeleton had been found, he does not believe that these caves were places of sepulture, but that the human remains were washed in at the same time as the bones of extinct quadrupeds, and that these lost species of mammalia coexisted on the earth with man.*

Bone-breccias formed in open fissures and caves.—Among the various modes in which the bones of animals become preserved independently of the agency of land floods and engulfed rivers, I may mention that open fissures often serve as natural pitfalls in which herbivorous animals perish. This may happen the more readily when they are chased by beasts of prey, or surprised while carelessly browsing on the shrubs which so often overgrow and conceal the edges of fissures.†

During the excavations recently made near Behat in India, the bones of two deer were found at the bottom of an ancient well which had been filled up with alluvial loam. Their horns were broken to pieces, but the jawbones and other

* The above was written in 1834, before the coexistence of man with the extinct animals had become a generally received doctrine. In my 'Antiquity of Man,' chap. iv., I have done more justice to Dr. Schmerling, and the reader will find there a full account of the Belgian caves which I re-examined in 1860.

† Buckland, Reliquiæ Diluvianæ, p. 25.

parts of the skeleton remained tolerably perfect. 'Their presence,' says Captain Cautley, 'is easily accounted for, as a great number of these and other animals are constantly lost in galloping over the jungles and among the high grass by falling into deserted wells.' *

Above the village of Selside, near Ingleborough, in Yorkshire, a chasm of enormous but unknown depth occurs in the scar-limestone, a member of the carboniferous series. 'The chasm,' says Professor Sedgwick, 'is surrounded by grassy shelving banks, and many animals, tempted towards its brink, have fallen down and perished in it. The approach of cattle is now prevented by a strong lofty wall; but there can be no doubt that, during the last two or three thousand years, great masses of bony breccia must have accumulated in the lower parts of the great fissure, which probably descends through the whole thickness of the scar-limestone, to the depth of perhaps five or six hundred feet.' †

When any of these natural pitfalls happen to communicate with lines of subterranean caverns, the bones, earth, and breccia may sink by their own weight, or be washed into the vaults below.

At the north extremity of the rock of Gibraltar are perpendicular fissures, on the ledges of which a number of hawks nestle and rear their young in the breeding season. They throw down from their nests the bones of small birds, mice, and other animals on which they feed, and these are gradually united into a breccia of angular fragments of the decomposing limestone with a cement of red earth.

At the pass of Escrinet in France, on the northern escarpment of the Coiron hills, near Aubenas, I have seen a breccia in the act of forming. Small pieces of disintegrating limestone are transported, during heavy rains, by a streamlet, to the foot of the declivity, where landshells are very abundant. The shells and pieces of stone soon become cemented together by stalagmite into a compact mass, and the talus thus formed is in one place 50 feet deep, and 500 yards wide. So firmly

* See above, p. 520.

† On the Lake Mountains of North of England, Geol. Soc., Jan. 5, 1831.

is the lowest portion consolidated, that it is quarried for millstones.

Recent stalagmitic limestone of Cuba.—One of the most singular examples of the recent growth of stalagmitic limestone in caves and fissures, is that described by Mr. R. C. Taylor, as observable on the north-east part of the island of Cuba.* The country there is composed of a white marble, in which are numerous cavities, partially filled with a calcareous deposit of a brick-red colour. In this red deposit are shells, or often the hollow casts of shells, chiefly referable to eight or nine species of land snails, a few scattered bones of quadrupeds, and, what is still more singular, marine univalve shells, often at the height of many hundred, or even one thousand feet above the sea. The following explanation is given of the gradual increase of this deposit. Land snails of the genera Helix, Cyclostoma, Pupa, and Clausilia, retire into the caves, the floors of which are strewed with myriads of their dead and unoccupied shells, at the same time that water infiltered through the mountain throws down carbonate of lime, enveloping the shells, together with fragments of the white limestone which occasionally falls from the roof. Multitudes of bats resort to the caves; and their dung, which is of a bright red colour (probably derived from the berries on which they feed), imparts its red hue to the mass. Sometimes also the Hutia, or great Indian rat of the island, dies and leaves its bones in the caves. 'At certain seasons the soldier-crabs resort to the sea-shore, and then return from their pilgrimage, each carrying with them, or rather dragging, the shell of some marine univalve for many a weary mile. They may be traced even at the distance of eight or ten miles from the shore, on the summit of mountains 1,200 feet high, like the pilgrims of the olden times, each bearing his shell to denote the character and extent of his wanderings.' By this means several species of marine testacea of the genera Trochus, Turbo, Littorina, and Monodonta, are conveyed into inland caverns, and enter into the composition of the newly formed rock.

* Notes on Geol. of Cuba, 1836, Phil. Mag., July, 1837.

CHAPTER XLVI.

IMBEDDING OF ORGANIC REMAINS IN SUBAQUEOUS DEPOSITS.

DIVISION OF THE SUBJECT—IMBEDDING OF TERRESTRIAL ANIMALS AND PLANTS —INCREASED SPECIFIC GRAVITY OF WOOD SUNK TO GREAT DEPTHS IN THE SEA —DRIFT-TIMBER CARRIED BY THE MACKENZIE INTO SLAVE LAKE AND POLAR SEA—FLOATING TREES IN THE MISSISSIPPI—IN THE GULF-STREAM—ON THE COASTS OF ICELAND, SPITZBERGEN, AND LABRADOR — SUBMARINE FORESTS — EXAMPLES ON COAST OF HAMPSHIRE AND IN BAY OF FUNDY — MINERALISATION OF PLANTS — IMBEDDING OF INSECTS — OF REPTILES — BONES OF BIRDS WHY RARE—IMBEDDING OF TERRESTRIAL QUADRUPEDS BY RIVER FLOODS—SKELETONS IN RECENT SHELL-MARL—IMBEDDING OF MAMMALIAN REMAINS IN MARINE STRATA.

Division of the subject.—Having treated of the imbedding of organic remains in deposits formed upon the land, I shall next consider the including of the same in deposits formed under water.

It will be convenient to divide this branch of our subject into three parts; considering, first, the various modes whereby the relics of *terrestrial* species may be buried in subaqueous formations; secondly, the modes whereby animals and plants inhabiting *fresh water* may be so entombed; thirdly, how *marine* species may become preserved in new strata.

The phenomena above enumerated demand a fuller share of attention than those previously examined, since the deposits which originate upon dry land are insignificant in thickness, superficial extent, and durability, when contrasted with those of subaqueous origin. At the same time, the study of the latter is beset with greater difficulties; for we are here concerned with the results of processes much farther removed from the sphere of ordinary observation. There is, indeed, no circumstance which so seriously impedes the acquisition of just views in our science as an habitual disregard of the important fact, that the reproductive effects of the principal

agents of change are confined to another element—to that larger portion of the globe, from which, by our very organisation, we are almost entirely excluded.*

IMBEDDING OF TERRESTRIAL PLANTS.

When a tree falls into a river from the undermining of the banks or from being washed in by a torrent or flood, it floats on the surface, not because the woody portion is specifically lighter than water, but because it is full of pores containing air. When soaked for a considerable time, the water makes its way into these pores, and the wood becomes *water-logged* and sinks. The time required for this process varies in different woods; but several kinds may be drifted to great distances, sometimes across the ocean, before they lose their buoyancy.

If wood be sunk to vast depths in the sea, it may be impregnated with water suddenly. Captain Scoresby informs us, in his Account of the Arctic Regions, that on one occasion a whale, on being harpooned, ran out all the line in the boat, which it then dragged under water, to the depth of several thousand feet, the men having just time to escape to a piece of ice. When the whale returned to the surface 'to blow,' it was struck a second time, and soon afterwards killed. The moment it expired it began to sink—an unusual circumstance, which was found to be caused by the weight of the sunken boat, which still remained attached to it. By means of harpoons and ropes the fish was prevented from sinking, until it was released from the weight by connecting a rope to the lines of the attached boat, which was no sooner done than the fish rose again to the surface. The sunken boat was then hauled up with great labour; for so heavy was it, that although before the accident it would have been buoyant when full of water, yet it now required a boat at each end to keep it from sinking. 'When it was hoisted into the ship, the paint came off the wood in large sheets; and the planks, which were of wainscot, were as completely soaked in every pore as if they had lain at the bottom of the sea since the

* See above, Vol. I. p. 97.

flood! A wooden apparatus that accompanied the boat in its progress through the deep, consisting chiefly of a piece of thick deal, about fifteen inches square, happened to fall overboard, and though it originally consisted of the lightest fir, sank in the water like a stone. The boat was rendered useless; even the wood of which it was built, on being offered to the cook for fuel, was tried and rejected as incombustible.'*

Captain Scoresby found that, by sinking pieces of fir, elm, ash, &c., to the depth of 4,000 and sometimes 6,000 feet, they became impregnated with sea-water, and when drawn up again, after immersion for an hour, would no longer float. The effect of this impregnation was to increase the dimensions as well as the specific gravity of the wood, every solid inch having increased one-twentieth in size and about seven-eighths in weight.†

Drift-wood of the Mackenzie River.—When timber is drifted down by a river, it is often arrested by lakes; and, becoming water-logged, it may sink and be imbedded in lacustrine strata, if any be there forming; sometimes a portion floats on till it reaches the sea. In the course of the Mackenzie River in the north-western part of North America, we have an example of vast accumulations of vegetable matter now in progress under both these circumstances.

In Slave Lake in particular, which is 200 miles long, the quantity of drift-timber brought down annually is enormous. 'As the trees,' says Sir John Richardson, 'retain their roots, which are often loaded with earth and stones, they readily sink, especially when water-soaked; and accumulating in the eddies, form shoals, which ultimately augment into islands. A thicket of small willows covers the new-formed island as soon as it appears above water, and their fibrous roots serve to bind the whole firmly together. Sections of these islands are annually made by the river; and it is interesting to study the diversity of appearances they present, according to their different ages. The trunks of the trees gradually decay until they are converted into a blackish-brown substance

* Account of the Arctic Regions, vol. ii. p. 193. † Ibid. p. 202.

resembling peat, but which still retains more or less of the fibrous structure of the wood; and layers of this often alternate with layers of clay and sand, the whole being penetrated, to the depth of four or five yards or more, by the long fibrous roots of the willows. A deposition of this kind, with the aid of a little infiltration of bituminous matter, would produce an excellent imitation of coal, with vegetable impressions of the willow-roots. What appeared most remarkable was the horizontal slaty structure that the old alluvial banks presented, and the *regular curve* that the strata assumed in places where there had been unequal subsidence.

'It was in the rivers only that we could observe sections of these deposits; but the same operation goes on, on a much more magnificent scale, in the lakes. A shoal of many miles in extent is formed on the south side of Athabasca Lake, by the drift-timber and vegetable débris brought down by the Elk River; and the Slave Lake itself must in process of time be filled up by the matters daily conveyed into it from Slave River. Vast quantities of drift-timber are buried under the sand at the mouth of the river, and enormous piles of it are accumulated on the shores of every part of the lake.'*

The banks of the Mackenzie display almost everywhere horizontal beds of wood coal, alternating with bituminous clay, gravel, sand, and friable sandstone; sections, in short, of such deposits as are now evidently forming at the bottom of the lakes which it traverses.

Notwithstanding that so much wood of the vast forests is intercepted by the lakes, a still greater mass of drift-wood is found where the Mackenzie reaches the sea, in lat. 69° N., where no wood grows at present except a few stunted willows. At the mouths of the river the alluvial matter has formed a barrier of islands and shoals, where we may expect a great formation of coal at some distant period.

The abundance of floating timber on the Mackenzie is owing to the direction and to the length of the course of this river, which runs from south to north, so that the sources of

* Sir J. Richardson's Geognost. Obs. on Capt. Franklin's Polar Expedition.

the stream lie in much warmer latitudes than its mouths. In the country, therefore, where the sources are situated, the frost breaks up at an earlier season, while yet the waters in the lower part of its course are ice-bound. Hence the current of water, rushing down northward, reaches a point where the thaw has not begun, and finding the channel of the river blocked up with ice, it overflows the banks, sweeping through forests of pines, and carrying away thousands of uprooted trees.

Drift-timber on coasts of Iceland, Spitzbergen, &c.—Although the Icelander can obtain no timber from the land, he is supplied with it abundantly by the ocean. An immense quantity of thick trunks of pines, firs, and other trees are thrown upon the northern coast of the island, especially upon North Cape and Cape Langanæs, and are then carried by the waves along these two promontories to other parts of the coast, so as to afford sufficiency of wood for fuel and for constructing boats. Timber is also carried to the shores of Labrador and Greenland; and Krantz assures us that the masses of floating wood thrown by the waves upon the island of John de Mayen often equal the whole of that island in extent.*

In a similar manner the bays of Spitzbergen are filled with drift-wood, which accumulates also upon those parts of the coast of Siberia that are exposed to the east, consisting of larch, pine, Siberian cedar, fir, and other kinds of trees, said to come from distant southern latitudes. Some of the trunks have been deprived of their bark by friction, but retain their roots and branches, and are in such a state of preservation as to form excellent building timber.† Parts of the branches and almost all the roots remain fixed to the pines which have been drifted into the North Sea, into latitudes too cold for the growth of such timber, but the trunks are usually barked.

The leaves and lighter portions of plants are seldom carried out to sea, in any part of the globe, except during tropical hurricanes among islands, and during the agitations of the

* Krantz, Hist. of Greenland, tom. i. pp. 53–54.

† Olafsen, Voyage to Iceland, tom. i.

atmosphere which sometimes accompany earthquakes and volcanic eruptions.

It will appear from these observations that, although the remains of terrestrial vegetation, borne down by aqueous causes from the land, are chiefly deposited at the bottom of lakes or at the mouths of rivers, yet a considerable quantity is drifted about in all directions by currents, and may become imbedded in any *marine* formation, or may sink down, when water-logged, to the bottom of the deepest abysses, and there accumulate.

It may be asked, whether we have any data for inferring that the remains of a considerable proportion of the existing species of plants will be permanently preserved, so as to be hereafter recognisable, supposing the strata now in progress to be at some future period upraised? To this enquiry it may be answered, that there are no reasons for expecting that more than a small number of the plants now flourishing on the globe will become fossilised; since the entire habitations of a great number of them are remote from lakes and seas, and even where they grow near to large bodies of water, the circumstances are quite accidental and partial which favour the imbedding and conservation of vegetable remains.

Submarine forest on coast of Hants.—Allusion has been made in the first volume, p. 548, to several localities on the British shores in which the remains of trees are seen in a vertical position submerged beneath the mean level of the sea, often with their roots attached. In many instances it is impossible to explain their submergence without assuming a change to have taken place in the relative level of land and sea. But such an hypothesis does not seem necessary in the case about to be described. My friend the Hon. Charles Harris—now Bishop of Gibraltar—discovered, in 1831, evident traces of a fir-wood beneath the mean level of the sea, at Bournemouth, in Hampshire, the formation having been laid open during a low spring tide. It is situated between the beach and a bar of sand about 200 yards off, and extends 50 yards along the shore, cropping out from beneath a bed of sand and shingle. It also lies in the

direct line of the Bournemouth Valley, from the termination of which it is separated by 200 yards of shingle and drift-sand. Down the valley flows a large brook, traversing near its mouth a considerable tract of rough, boggy, and heathy ground, which produces a few birch trees, and a great abundance of the bog-myrtle (*Myrica gale*). In that part of the submerged peat which was exposed at low water were seen twenty or more large stumps of fir, from one to two feet in height, the roots and bases of which still retain their bark. The sap-wood of these is soft and spongy, but perfectly white, and exhibiting its original character. The heart-wood is exceedingly hard and tough, and in the larger stumps, of a greenish hue, saturated with moisture, and exhaling a strong odour of sulphuretted hydrogen. 'This odour, and the greenish colour, are dependent,' says Bishop Harris, 'on an incipient formation of iron pyrites, which is proceeding with some rapidity in the peaty stratum beneath. The pyrites occurs in small concretions, enclosing both roots and fibres. In some instances it may be seen filling up the hollow stems of grasses, in others it has penetrated to the heart of pieces of fir-wood, two or three inches in diameter, following the grain of the wood and often supplying its place, so as not to be easily perceivable till broken.'

Seventy-six rings of annual growth were counted in a transverse section of one of the trees, which was fourteen inches in diameter. Besides the stumps and roots of fir, rushes, and other compressed vegetable matter and pieces of alder and birch are found in the peat. In the centre of the formation the peat was pierced two feet and a half without being passed through; towards its edges, however, it is seen resting on a stratum of bluish pebbles, clay and sand, which crops out also on its seaward side, and is precisely similar to the sand and pebbles that occur on the adjoining heaths. The whole formation was shown to have existed 40 years before, in the same situation and presenting the same appearances as in 1831, and I learned from Bishop Harris (Feb. 1868) that on several occasions he had since revisited the spot and again observed the stumps *in situ*.

Now as the sea is encroaching on this shore, we may

suppose that at some former period the Bournemouth Valley extended farther, and that its extremity consisted, as at present, of rough and boggy ground, partly clothed with fir-trees. It is also probable that the whole of this rested on the sand and pebbles already mentioned, and that the sea, in its progressive encroachments, eventually laid bare, at low water, the foundations of this marshy ground; in which case, much of the sand constituting these foundations might have been washed out by the rapid descent of the fresh water through them at the fall of the tide. The superstratum of vegetable matter being matted and bound together by the roots of trees, would not be washed away, but might be undermined, and thus sink down below the level of the sea, until the waves washed sand and shingle over it. This operation may have also been assisted by the occasional damming up of the brook by the sand and shingle thrown up during storms. Bishop Harris informs me that such an obstruction actually occurred in the years 1818 and 1824, and the bed of the brook was completely obliterated. On these occasions an artificial channel was immediately cut; had this, however, not been done, the lower part of the valley would have been flooded; and by this means the under strata would have become more saturated with water, and the increased pressure would have augmented the tendency of the water to escape through them. In confirmation of this hypothesis we may observe, that small streams of fresh water often pass under the sands of the sea-beach, so that they may be crossed dryshod, whilst the water where it issues again may be seen to carry out sand and pebbles with great rapidity.

The Rev. W. B. Clarke, after examining the Bournemouth submarine peat and several other similar deposits on the north side of Poole Harbour, came, in 1838, to a conclusion, like that adopted by Bishop Harris and myself, that they had been sunk and submerged in modern times by the undermining of the sandy strata on which they rested, and did not imply a general subsidence or change of level in that part of the coast.*

* On Peat-bogs and Submarine Forests of Bournemouth. Rev. W. B. Clarke, Proc. of Geol. Soc., p. 599. 1838.

Submerged forest in Bay of Fundy.—One of the best authenticated examples of an old upland soil with trees, now covered by about thirty feet of water at high tide, occurs at Fort Lawrence in the Bay of Fundy, near the boundary between Nova Scotia and New Brunswick. Dr. Dawson, an experienced geologist and most careful observer, has shown that below layers of marine marsh-alluvium containing shells of *Sanguinolaria fusca* (a bivalve shell probably identical with *Tellina Baltica*, Linn.), there is a bed of tough blue clay, and beneath it an old peaty soil with erect trunks of trees and roots. All the stumps observed were those of pine and beech (*Pinus strobus* and *Fagus ferruginea*), trees indicative rather of dry upland than of swampy ground. The largest stump of a pine measured two and a half feet in diameter and exhibited about 200 rings of annual growth. Dr. Dawson counted thirty stumps in a limited area, and the same formation occurs at so many points as to lead him to infer that there has been a very general sinking down of the land in the same district. The powerful tides of the Bay of Fundy, rising and falling 40 feet, cause this formation to be peculiarly well exposed to view at many points, the deposit being laid bare by the continual encroachments of the sea.*

Mineralisation of plants.—Although the botanist and chemist have as yet been unable to explain fully the manner in which wood becomes petrified, it is nevertheless ascertained that, under favourable circumstances, the lapidifying process is now continually going on. A piece of wood was procured by Mr. Stokes, from an ancient Roman aqueduct in Westphalia, in which some portions were converted into spindle-shaped bodies, consisting of carbonate of lime, while the rest of the wood remained in a comparatively unchanged state.† It appears that in some cases the most perishable, in others the most durable, portions of plants are preserved, variations which doubtless depend on the time when the mineral matter was supplied. If introduced immediately,

* Dawson, Submerged Forest at Fort Lawrence, Quart. Geol. Journ., vol. xi. p. 119. 1854.

† Geol. Trans., second series, vol. v. p. 212.

on the first commencement of decomposition, then the most destructible parts are lapidified, while the more durable do not waste away till afterwards, when the supply has failed, and so never become petrified. The converse of these circumstances gives rise to exactly opposite results.

Professor Göppert, of Breslau, has instituted a series of valuable experiments, in which he has succeeded in producing some very remarkable imitations of fossil petrifactions. He placed recent ferns between soft layers of clay, dried these in the shade, and then slowly and gradually heated them, till the clay was red-hot. The result was the production of so perfect a counterpart of fossil plants as might have deceived an experienced geologist. According to the different degrees of heat applied, the plants were obtained in a brown or perfectly carbonised condition; and sometimes, but more rarely, they were in a black shining state, adhering closely to the layer of clay. If the red heat was sustained until all the organic matter was burnt up, only an impression of the plant remained.

The same chemist steeped plants in a moderately strong solution of sulphate of iron, and left them immersed in it for several days, until they were thoroughly soaked in the liquid. They were then dried, and kept heated until they would no longer shrink in volume, and until every trace of organic matter had disappeared. On cooling them he found that the oxide formed by this process had taken the form of the plants. A variety of other experiments were made by steeping animal and vegetable substances in siliceous, calcareous, and metallic solutions, and all tended to prove that the mineralisation of organic bodies can be carried much farther in a short time than had been previously supposed.*

Imbedding of insects, reptiles, and birds.—I have observed the elytra and other parts of beetles in a band of fissile clay, separating two beds of recent shell-marl, in the Loch of Kinnordy in Forfarshire. Amongst these, Mr. Curtis recognised *Elater lineatus* and *Atopa cervina*, species still living in Scotland. These, as well as other remains which accompanied

* Göppert, Poggendorff's Annalen der Physik und Chemie, vol. xxxviii. part iv., Leipsic, 1836. See also Lyell's 'Student's Elements,' p. 45.

them, appear to belong to terrestrial, not aquatic, species, and must have been carried down in muddy water during an inundation. In the lacustrine peat of the same locality, the elytra of beetles are not uncommon; but in the deposits of drained lakes generally, and in the silt of our estuaries, the relics of this class of the animal kingdom are rare. In the blue clay of very modern origin of Lewes Levels, Dr. Mantell has found the Indusia, or cases of the larvæ of Phryganea, in abundance, with minute shells belonging to the genera Planorbis, Limnea, &c., adhering to them.*

When speaking of the migrations of insects, I pointed out that an immense number are floated into lakes and seas by rivers, or blown by winds far from the land; but they are so buoyant that we can only suppose them, under very peculiar circumstances, to sink to the bottom before they are either devoured by insectivorous animals or decomposed.

As the bodies of several crocodiles were found in the mud brought down to the sea by the river inundation which attended an earthquake in Java, in the year 1699, we may imagine that extraordinary floods of mud may stifle many individuals of the shoals of alligators and other reptiles which frequent lakes and the deltas of rivers in tropical climates. Thousands of frogs were found leaping about among the wreck carried into the sea by the inundations in Morayshire, in 1829;† and it is evident that whenever a sea-cliff is undermined, or land is swept by other violent causes into the sea, land reptiles may be carried in.

We might have anticipated that the imbedding of the remains of birds in new strata would be of very rare occurrence, for their powers of flight insure them against perishing by numerous casualties to which quadrupeds are exposed during floods; and if they chance to be drowned, or to die when swimming on the water, it will scarcely ever happen that they will be submerged so as to become preserved in sedimentary deposits. In consequence of the hollow tubular structure of their bones and the quantity of their feathers they are extremely light in proportion to their volume;

* Trans. Geol. Soc., vol. iii., part i. p. 201, second series.

† Sir T. D. Lauder's account, 2nd ed., p. 312.

so that when first killed they do not sink to the bottom like quadrupeds, but float on the surface until the carcass either rots away or is devoured by predaceous animals. To these causes we may ascribe the absence of any vestige of the bones of birds in the recent marl formations of Scotland; although these lakes, until the moment when they were artificially drained, were frequented by a great abundance of water-fowl.

IMBEDDING OF TERRESTRIAL QUADRUPEDS.

River inundations recur in most climates at very irregular intervals, and expend their fury on those rich alluvial plains, where herds of herbivorous quadrupeds congregate together. These animals are often surprised; and, being unable to stem the current, are hurried along until they are drowned, when they sink at first immediately to the bottom. Here their bodies are drifted along, together with sediment, into lakes or seas, and may then be covered by a mass of mud, sand, and pebbles, thrown down upon them. If there be no sediment superimposed, the gases generated by putrefaction usually cause the bodies to rise again to the surface about the ninth or at latest the fourteenth day. The pressure of a thin covering of mud would not be sufficient to retain them at the bottom; for we see the putrid carcasses of dogs and cats, even in rivers, floating with considerable weights attached to them, and in sea-water they would be still more buoyant.

Where the body is so buried in drift-sand, or mud accumulated upon it, as never to rise again, the skeleton may be preserved entire; but if it comes again to the surface while in the process of putrefaction, the bones commonly fall piecemeal from the floating carcass, and may in that case be scattered at random over the bottom of the lake, estuary, or sea; so that a jaw may afterwards be found in one place, a rib in another, a humerus in a third—all included, perhaps, in a matrix of fine materials, where there may be evidence of very slight transporting power in the current, or even of none, but simply of some chemical precipitate.

A large number of the bodies of drowned animals, if they float into the sea or a lake, especially in hot climates, are

instantly devoured by sharks, alligators, and other carnivorous animals, which may have power to digest even the bones; but during extraordinary floods, when the greatest number of land animals are destroyed, the waters are commonly so turbid, especially at the bottom of the channel, that even aquatic species are compelled to escape into some retreat where there is clearer water, lest they should be stifled. For this reason, as well as the rapidity of sedimentary deposition at such seasons, the probability of carcasses becoming permanently imbedded is considerable.

In some instances, the skeletons of quadrupeds are met with abundantly in recent shell-marls in Scotland, where we cannot suppose them to have been imbedded by the action of rivers or floods. They all belong to species which now inhabit, or are known to have been indigenous in Scotland. The remains of several hundred skeletons have been procured within the last century from five or six small lakes in Forfarshire, where shell-marl has been worked. Those of the stag (*Cervus Elaphus*) are most numerous; and if the others be arranged in the order of their relative abundance, they will follow nearly thus—the ox, the boar, the horse, the sheep, the dog, the hare, the fox, the wolf, and the cat. The beaver seems extremely rare; but it has been found in the shell-marl of Loch Marlie, in Perthshire, and in the parish of Edrom, in Berwickshire.

In the greater part of these lake-deposits there are no signs of floods; and the expanse of water was originally so confined that the smallest of the above-mentioned quadrupeds could have crossed by swimming from one shore to the other. Deer, and such species as take readily to the water, may often have been mired in trying to land, where the bottom was soft and quaggy, and in their efforts to escape may have plunged deeper into the marly bottom. But many individuals, I suspect, of different species, have fallen in when crossing the frozen surface in winter; for nothing can be more treacherous than the ice when covered with snow, in consequence of the springs, which are numerous, and which, retaining always an equal temperature, cause the ice, in certain spots, to be extremely thin, while in every other

part of the lake it is strong enough to bear the heaviest weights.

Flood in the Solway Firth, 1794.—One of the most memorable floods of modern date, in our island, is that which visited part of the southern borders of Scotland, on the 24th of January, 1794, and which spread particular devastation over the country adjoining the Solway Firth.

We learn from the account of Captain Napier, that the heavy rains had swollen every stream which entered the Firth of Solway; so that the inundation not only carried away a great number of cattle and sheep, but many of the herdsmen and shepherds, washing down their bodies into the estuary. After the storm, when the flood subsided, an extraordinary spectacle was seen on a large sand-bank called 'the beds of Esk,' where there is a meeting of the tidal waters, and where heavy bodies are usually left stranded after great floods. On this single bank were found collected together the bodies of 9 black cattle, 3 horses, 1,840 sheep, 45 dogs, 180 hares, besides a great number of smaller animals, and mingled with the rest, the corpses of two men and one woman.*

Floods in Scotland, 1829.—In those more recent floods in Scotland, in August, 1829, whereby a fertile district on the east coast became a scene of dreadful desolation, a vast number of animals and plants were washed from the land, and found scattered about after the storm, around the mouths of the principal rivers. An eye-witness thus describes the scene which presented itself at the mouth of the Spey, in Morayshire:—'For several miles along the beach crowds were employed in endeavouring to save the wood and other wreck with which the heavy-rolling tide was loaded; whilst the margin of the sea was strewed with the carcasses of domestic animals, and with millions of dead hares and rabbits.'†

Savannahs of South America.—We are informed by Humboldt, that during the periodical swellings of the large rivers

* Treatise on Practical Store Farming, p. 25.

† Sir T. D. Lauder's Floods in Morayshire, 1829; and above, Vol. I. p. 345.

in South America great numbers of quadrupeds are annually drowned. Of the wild horses, for example, which graze in immense troops in the savannahs, or level grassy plains, thousands are said to perish when the river Apure, a tributary of the Orinoco, is swollen, before they have time to reach the rising ground of the Llanos. The mares, during the season of high water, may be seen, followed by their colts, swimming about and feeding on the grass, of which the top alone waves above the waters. In this state they are pursued by crocodiles; and their thighs frequently bear the prints of the teeth of these carnivorous reptiles. 'Such is the pliability,' observes the celebrated traveller, 'of the organisation of the animals which man has subjected to his sway, that horses, cows, and other species of European origin, lead, for a time, an amphibious life, surrounded by crocodiles, water-serpents, and manatees. When the rivers return again into their beds, they roam in the savannah, which is then spread over with a fine odoriferous grass, and enjoy, as in their native climate, the renewed vegetation of spring.' *

Floods of the Paranà.—The great number of animals which are drowned in seasons of drought in the tributaries of the Plata was before mentioned. Sir W. Parish states that the Paranà, flowing from the mountains of Brazil to the estuary of the Plata, is liable to great floods, and during one of these, in the year 1812, vast quantities of cattle were carried away, 'and when the waters began to subside, and the islands which they had covered became again visible, the whole atmosphere for a time was poisoned by the effluvia from the innumerable carcasses of skunks, capybaras, tigers, and other wild beasts which had been drowned.'†

Floods of the Ganges.—We find it continually stated, by those who describe the Ganges and Burrampooter, that these rivers carry before them, during the flood season, not only floats of reeds and timber, but dead bodies of men, deer, and oxen.‡

Java, 1699.—I have already referred to the effects of a flood which attended an earthquake in Java in 1699, when

* Humboldt's Pers. Nar., vol. iv. p. 394.

† Buenos Ayres and La Plata, p. 187.

‡ Malte-Brun, Geog., vol. iii. p. 22.

the turbid waters of the Batavian river destroyed all the fish except the carp; and when drowned buffaloes, tigers, rhinoceroses, deer, apes, and other wild beasts were brought down to the sea-coast by the current, with several crocodiles which had been stifled in the mud. (See above, p. 159.)

On the western side of the same island, in the territory of Galongoon, in the Regencies, a more recent volcanic eruption (that of 1822, before described—see above, p. 57) was attended by a flood, during which the river Tandoi bore down hundreds of carcasses of rhinoceroses and buffaloes, and swept away more than 100 men and women from a multitude assembled on its banks to celebrate a festival. Whether the bodies reached the sea, or were deposited, with drift matter, in some of the large intervening alluvial plains, we are not informed.*

Sumatra.—'On the coast of Orissa,' says Heynes, 'I have seen tigers and whole herds of black cattle carried along by what are called freshes, and trees of immense size.'†

Virginia, 1771.—I might enumerate a great number of local deluges that have swept through the fertile lands bordering on large rivers, especially in tropical countries, but I should surpass the limits assigned to this work. I may observe, however, that the destruction of the islands, in rivers, is often attended with great loss of life. Thus when the principal river in Virginia rose, in 1771, to the height of 25 feet above its ordinary level, it swept entirely away Elk Island, on which were 700 head of quadrupeds,—horses, oxen, sheep, and hogs,—and nearly 100 houses.‡

The reader will gather, from what was before said respecting the deposition of sediment by aqueous causes, that the greater number of the remains of quadrupeds drifted away by rivers must be intercepted by lakes before they reach the sea, or buried in freshwater formations near the mouths of rivers. If they are carried still farther, the probabilities are increased of their rising to the surface in a

* This account I had from Mr. Baumhauer, Director-General of Finances in Java.

† Tracts on India, p. 397.

‡ Scots Mag., vol. xxxiii.

state of putrefaction, and, in that case, of being there devoured by aquatic beasts of prey, or of subsiding into some spots whither no sediment is conveyed, and, consequently, where every vestige of them will, in the course of time, disappear.

Mammalian remains in marine strata.—As the bones of mammalia are often so abundantly preserved in peat, and such lakes as have just been described, the encroachments of the sea upon a coast must sometimes throw down the imbedded skeletons, so that they may be carried away by tides and currents, and entombed in submarine formations. Some of the smaller quadrupeds, also, which burrow in the ground, as well as reptiles and every species of plant, are liable to be cast down into the waves by this cause, which must not be overlooked, although, perhaps, of comparatively small importance amongst the numerous agents whereby terrestrial organic remains are included in submarine strata.

During the great earthquake of Conception in 1835, some cattle, which were standing on the steep sides of the island of Quiriquina, were rolled by the shock into the sea, while on a low island at the head of the Bay of Conception seventy animals were washed off by a great wave and drowned.*

* Darwin's Journal, p. 372, 2nd ed. 1845, p. 304.

CHAPTER XLVII.

IMBEDDING OF THE REMAINS OF MAN AND HIS WORKS IN SUBAQUEOUS STRATA.

DRIFTING OF HUMAN BODIES TO THE SEA BY RIVER INUNDATIONS—HOW HUMAN CORPSES MAY BE PRESERVED IN RECENT DEPOSITS—FOSSIL SKELETONS OF MEN—NUMBER OF WRECKED VESSELS—FOSSIL CANOES, SHIPS, AND WORKS OF ART—CHEMICAL CHANGES WHICH METALLIC ARTICLES HAVE UNDERGONE AFTER LONG SUBMERGENCE—IMBEDDING OF CITIES AND FORESTS IN SUBAQUEOUS STRATA BY SUBSIDENCE—EARTHQUAKE OF CUTCH IN 1819—BURIED TEMPLES OF CASHMERE—BERKELEY'S ARGUMENTS FOR THE RECENT DATE OF THE CREATION OF MAN—MONUMENTS OF PRE-HISTORIC MAN DISCOVERED IN POST-TERTIARY STRATA.

I SHALL now proceed to enquire in what manner the mortal remains of man and the works of his hands may be permanently preserved in subaqueous strata. Of the many hundred million human beings which perish in the course of every century on the land, every vestige is usually destroyed in a few thousand years; but of the smaller number that perish in the waters, a certain proportion must be entombed under circumstances that may enable parts of them to endure throughout entire geological epochs.

The bodies of men, together with those of the inferior animals, are occasionally washed down during river inundations into seas and lakes. Belzoni witnessed a flood on the Nile in September, 1818, where, although the river rose only three feet and a half above its ordinary level, several villages, with some hundreds of men, women, and children, were drowned.* It was before mentioned that a rise of six feet of water in the Ganges, in 1763, was attended with a much greater loss of life. (See above, Vol. I. p. 472.)

In the year 1771, when the inundations in the north of

* Narrative of Discovery in Egypt, &c., London, 1820.

England appear to have equalled the floods of Morayshire in 1829, a great number of houses and their inhabitants were swept away by the rivers Tyne, Cam, Wear, Tees, and Greta; and no less than twenty-one bridges were destroyed in the courses of these rivers. At the village of Bywell the flood tore the dead bodies and coffins out of the churchyard, and bore them away, together with many of the living inhabitants. During the same tempest an immense number of cattle, horses, and sheep were also transported to the sea, while the whole coast was covered with the wreck of ships. Four centuries before (in 1338), the same district had been visited by a similar continuance of heavy rains followed by disastrous floods, and it is not improbable that these catastrophes may recur periodically, though after uncertain intervals. As the population increases, and buildings and bridges are multiplied, we must expect the loss of lives and property to augment.*

Preservation of human bodies in the bed of the sea.—If to the hundreds of human bodies committed to the deep in the way of ordinary burial we add those of individuals lost by shipwrecks, we shall find that, in the course of a single year, a great number of human remains are consigned to the subaqueous regions. I shall hereafter advert to a calculation by which it appears that more than 500 *British* vessels alone, averaging each a burden of about 120 tons, were wrecked, and sunk to the bottom, *annually* between the years 1793 and 1829. Of these the crews for the most part escape, although it sometimes happens that all perish. In one great naval action several thousand individuals sometimes share a watery grave.

Many of these corpses are instantly devoured by predaceous fish, sometimes before they reach the bottom; still more frequently when they rise again to the surface, and float in a state of putrefaction. Many decompose on the floor of the ocean, in places where no sediment is thrown down upon them; but if they fall upon a reef where corals and shells are becoming agglutinated into a solid rock, or subside where the

* Scots Mag. vol. xxxiii. 1771.

delta of a river is advancing, they may be preserved for an incalculable series of ages.

Often at the distance of a few hundred feet from a coral reef, where wrecks are not unfrequent, there are no soundings at the depth of many hundred fathoms. Canoes, merchant vessels, and ships of war may have sunk and have been enveloped, in such situations, in calcareous sand and breccia, detached by the breakers from the summit of a submarine mountain. Should a volcanic eruption happen to cover such remains with ashes and sand, and a current of lava be afterwards poured over them, the ships and human skeletons might remain uninjured beneath the superincumbent mass, like the houses and works of art in the subterranean cities of Campania. Already many human remains may have been thus preserved beneath formations more than 1,000 feet in thickness; for, in some volcanic archipelagos, a period of thirty or forty centuries might well be supposed sufficient for such an accumulation.

Even on that part of the floor of the ocean to which no accession of drift matter is carried (a part which probably constitutes, at any given period, by far the larger proportion of the whole submarine area), there are circumstances accompanying a wreck which favour the conservation of skeletons. For when the vessel fills suddenly with water, especially in the night, many persons are drowned between decks and in their cabins, so that their bodies are prevented from rising again to the surface. The vessel often strikes upon an uneven bottom and is overturned; in which case the ballast, consisting of sand, shingle, and rock, or the cargo, frequently composed of heavy and durable materials, may be thrown down upon the carcasses. In the case of ships of war, cannon, shot, and other warlike stores may press down with their weight the timbers of the vessel as they decay, and beneath these and the metallic substances the bones of man may be preserved.

Power of human remains to resist decay.—There can be no doubt that human remains are as capable of resisting decay as are the harder parts of the inferior animals; and I have already cited the remark of Cuvier, that 'in ancient fields of

battle the bones of men have suffered as little decomposition as those of horses which were buried in the same grave.' (See above, Vol. I. p. 165.) In the delta of the Ganges bones of men have been found in digging a well at the depth of 90 feet; * but as that river frequently shifts its course and fills up its ancient channels, we are not called upon to suppose that these bodies are of extremely high antiquity, or that they were buried when that part of the surrounding delta where they occur was first gained from the sea.

Several skeletons of men, more or less mutilated, have been found in the West Indies, on the north-west coast of the main land of Guadaloupe, in a kind of rock which is known to be forming daily, and which consists of minute fragments of shells and corals, incrusted with a calcareous cement resembling travertin, by which also the different grains are bound together. The lens shows that some of the fragments of coral composing this stone still retain the same red colour which is seen in the reefs of living coral which surround the island. The shells belong to species of the neighbouring sea intermixed with some terrestrial kinds which now live on the island, and among them is the *Bulimus Guadaloupensis* of Férussac. The human skeletons still retain some of their animal matter, and all their phosphate of lime. One of them, of which the head is wanting, may now be seen in the British Museum, and another in the Royal Cabinet at Paris. According to M. König, the rock in which the former is enclosed is harder under the mason's saw and chisel than statuary marble. It is described as forming a kind of glacis, probably an indurated beach, which slants from the steep cliffs of the island to the sea, and is nearly all submerged at high tide.

Number of wrecked vessels.—When we reflect on the number of curious monuments consigned to the bed of the ocean in the course of every naval war from the earliest times, our conceptions are greatly raised respecting the multiplicity of lasting memorials which man is leaving of his labours. During our last great struggle with France, thirty-two of

* Von Hoff, vol. i. p. 379.

our ships of the line went to the bottom in the space of twenty-two years, besides seven 50-gun ships, eighty-six frigates, and a multitude of smaller vessels. The navies of the other European powers, France, Holland, Spain, and Denmark, were almost annihilated during the same period, so that the aggregate of their losses must have many times exceeded that of Great Britain. In every one of these ships were batteries of cannon constructed of iron or brass, whereof a great number had the dates and places of their manufacture inscribed upon them in letters cast in metal. In each there were coins of copper, silver, and often many of gold, capable of serving as valuable historical monuments; in each were an infinite variety of instruments of the arts of war and peace; many formed of materials, such as glass and earthenware, capable of lasting for indefinite ages when once removed from the mechanical action of the waves, and buried under a mass of matter which may exclude the corroding action of sea-water. The quantity, moreover, of timber which is conveyed from the land to the bed of the sea by the sinking of ships of a large size is enormous; for it is computed that 2,000 tons of wood are required for the building of one 74-gun ship; and reckoning fifty oaks of 100 years' growth to the acre, it would require forty acres of oak forest to build one of these vessels.*

But it would be an error to imagine that the fury of war is more conducive than the peaceful spirit of commercial enterprise to the accumulation of wrecked vessels in the bed of the sea. From an examination of Lloyd's lists, from the year 1793 to the commencement of 1829, the late Admiral Smyth ascertained that the number of *British vessels* alone lost during that period amounted on an average to no less than one and a half *daily*; an extent of loss which would hardly have been anticipated, although we learn from Moreau's tables that the number of merchant vessels employed at that time, in the navigation of England and Scotland, amounted to about 20,000, having one with another a mean burden of 120 tons.† According to Lloyd's list for the

* Quart. Journ. of Agricult., No. ix. p. 433.

† Cæsar Moreau's Tables of the Navigation of Great Britain.

years 1829, 1830, and 1831, no less than 1,953 vessels were lost in those three years, their average tonnage being about 150 tons, or in all nearly 300,000 tons, being at the enormous rate of 100,000 tons annually of the merchant vessels of one nation only.

Out of 551 ships of the Royal Navy lost to the country during the period above mentioned, only 160 were taken or destroyed by the enemy, the rest having either stranded or foundered, or having been burnt by accident: a striking proof that the dangers of our naval warfare, however great, may be far exceeded by the storm, the shoal, the lee-shore, and all the other perils of the deep.*

In the wreck register for 1866, published by the Board of Trade, the number of shipwrecks and other casualties at sea is stated at no less than 1,860 on the coast of the United Kingdom and in the adjacent seas, and the number of persons drowned as 896, showing how greatly the loss increases from increasing activity in commerce.

Buried ships, canoes, and works of art.—When a vessel is stranded in shallow water, it usually becomes the nucleus of a sandbank, as has been exemplified in several of our harbours, and this circumstance tends greatly to its preservation. Between the years 1780 and 1790 a vessel from Purbeck, laden with 300 tons of stone, struck on a shoal off the entrance of Poole Harbour and foundered; the crew were saved, but the vessel and cargo remain to this day at the bottom. Since that period the shoal at the entrance of the harbour has so extended itself in a westerly direction towards Peveril Point in Purbeck, that the navigable channel is thrown a mile nearer that point.† The cause is obvious: the tidal current deposits the sediment with which it is charged around any object which checks its velocity. Matter also drifted along the bottom is arrested by any obstacle, and accumulates round it, just as the African sand-winds, before described, raise a small hillock over the carcass of every dead camel exposed on the surface of the desert.

I before alluded to an ancient Dutch vessel, discovered in

* I give these results on the authority of the late Admiral Smyth, R.N.

† This account I received from Bishop Harris.

the deserted channel of the river Rother, in Sussex, of which the oak wood was much blackened, but its texture unchanged. (See above, Vol. I. p. 533.) The interior was filled with fluviatile silt, as was also the case in regard to a vessel discovered in a former bed of the Mersey, and another disinterred where the St. Katherine Docks are excavated in the alluvial plain of the Thames. In like manner many ships have been found preserved entire in modern strata, formed by the silting up of estuaries along the southern shores of the Baltic, especially in Pomerania. Between Bromberg and Nakel, for example, a vessel and two anchors in a very perfect state were dug up far from the sea.*

Several vessels have been lately detected half buried in the delta of the Indus, in the numerous deserted branches of that river, far from where the stream now flows. One of these, found near Vikkar in Sinde, was 400 tons in burden, old-fashioned, and pierced for fourteen guns, and in a region where it had been matter of dispute whether the Indus had ever been navigable by large vessels.†

At the mouth of a river in Nova Scotia, a schooner of 32 tons, laden with live stock, was lying with her side to the tide, when the bore, or tidal wave, which rises there about 10 feet in perpendicular height, rushed into the estuary, and overturned the vessel, so that it instantly disappeared. After the tide had ebbed, the schooner was so totally buried in the sand, that the taffrel or upper rail over the stern was alone visible.‡ We are informed by Leigh that, on draining Martin Mere, a lake eighteen miles in circumference, in Lancashire, a bed of marl was laid dry, wherein no fewer than eight canoes were found imbedded. In figure and dimensions they were not unlike those now used in America. In a morass about nine miles distant from this mere a whetstone and an axe of mixed metal were dug up.§ In Ayrshire, also, three canoes were found in Loch Doon early in the present century; and during the year 1831 four others, each

* Von Hoff, vol. i. p. 368.

† Lieut. Carless, Geograph. Journ. vol. viii. p. 338.

‡ Silliman's Geol. Lectures, p. 78, who cites Penn.

§ Leigh's Lancashire, p. 17, A.D. 1700.

hewn out of a single oak-tree. They were 23 feet in length, $2\frac{1}{2}$ in depth, and nearly 4 feet in breadth at the stern. In the mud which filled one of them were found a war-club of oak and a stone battle-axe. A canoe of oak was also found, in 1820, in peat overlying the shell-marl of the Loch of Kinnordy in Forfarshire.*

Manner in which ships may be preserved in a deep sea.—It is extremely possible that the submerged woodwork of ships which have sunk where the sea is two or three miles deep has undergone greater chemical changes in an equal space of time than in the cases above mentioned; for the experiments of Scoresby show that wood may at certain depths be impregnated in a single hour with salt water, so that its specific gravity is entirely altered. (See above, p. 532.) It may often happen that springs charged with carbonate of lime, silex, and other mineral ingredients, may issue at great depths, in which case every pore of the vegetable tissue may be injected with the lapidifying liquid, whether calcareous or siliceous, before the smallest decay commences. The conversion, also, of wood into lignite is probably more rapid under enormous pressure. But the change of the timber into lignite or coal would not prevent the original form of a ship from being distinguished; for as we find, in strata of the carboniferous era, the bark of the hollow reed-like trees converted into coal, and the central cavity filled with sandstone, so might we trace the outline of a ship in coal; while in the indurated mud, sandstone, or limestone, filling the interior, we might discover instruments of human art, ballast consisting of rocks foreign to the rest of the stratum, and other contents of the ship.

Submerged metallic substances.—Many of the metallic substances which fall into the waters probably lose, in the course of ages, the forms artificially imparted to them; but under certain circumstances these may be preserved for indefinite periods. The cannon enclosed in a calcareous rock, drawn up from the delta of the Rhone, which is now in the museum at Montpellier, might probably have endured as long as the

* Geol. Trans. second series, vol. ii. p. 87. For buried canoes near Glasgow see 'Antiquity of Man,' p. 48.

calcareous matrix; but even if the metallic matter had been removed, and had entered into new combinations, still a mould of its original shape would have been left, corresponding to those impressions of shells which we see in rocks, from which all the carbonate of lime has been subtracted. About the year 1776, says Mr. King, some fishermen, sweeping for anchors in the Gull-stream (a part of the sea near the Downs), drew up a very curious old swivel gun, nearly eight feet in length. The barrel, which was about five feet long, was of brass; but the handle by which it was traversed was about three feet in length, and the swivel and pivot on which it turned were of iron. Around these latter were formed incrustations of sand converted into a kind of stone, of exceedingly strong texture and firmness; whereas round the barrel of the gun, except where it was near adjoining to the iron, there were no such incrustations, the greater part of it being clean, and in good condition, just as if it had still continued in use. In the incrusting stone, adhering to it on the outside, were a number of shells and corallines, 'just as they are often found in a fossil state.' These were all so strongly attached, that it required as much force to separate them from the matrix 'as to break a fragment off any hard rock.'*

In the year 1745, continues the same writer, the Fox man-of-war was stranded on the coast of East Lothian, and went to pieces. About thirty-five years afterwards a violent storm laid bare a part of the wreck, and threw up near the place several masses, 'consisting of iron, ropes, and balls,' covered over with ochreous sand, concreted and hardened into a kind of stone. The substance of the rope was very little altered. The consolidated sand retained perfect impressions of parts of an iron ring, 'just as impressions of extraneous fossil bodies are found in various kinds of strata.'†

After a storm in the year 1824, which occasioned a considerable shifting of the sands near St. Andrew's, in Scotland, a gun-barrel of ancient construction was found, which is conjectured to have belonged to one of the wrecked vessels of

* Phil. Trans., 1779. † Ibid, vol. lxix. 1779.

the Spanish Armada. It is now in the museum of the Antiquarian Society of Scotland, and is incrusted over by a thin coating of sand, the grains of which are cemented by brown ferruginous matter. Attached to this coating are fragments of various shells, as of the common Cardium, Mya, &c.

Many other examples are recorded of iron instruments taken up from the bed of the sea near the British coast, incased by a thick coating of conglomerate, consisting of pebbles and sand, cemented by oxide of iron.

Dr. Davy describes a bronze helmet, of the antique Grecian form, taken up in 1825, from a shallow part of the sea, between the citadel of Corfu and the village of Castrades. Both the interior and exterior of the helmet were partially incrusted with shells and a deposit of carbonate of lime. The surface generally, both under the incrustation and where freed from it, was of a variegated colour, mottled with spots of green, dirty white, and red. On minute inspection with a lens, the green and red patches proved to consist of crystals of the red oxide and carbonate of copper, and the dirty white chiefly of oxide of tin.

The mineralising process, says Dr. Davy, which has produced these new combinations, has, in general, penetrated very little into the substance of the helmet. The incrustation and rust removed, the metal is found bright beneath; in some places considerably corroded, in others very slightly. It proves, on analysis, to be copper alloyed with 18·5 per cent. of tin. Its colour is that of our common brass, and it possesses a considerable degree of flexibility.

'It is a curious question,' he adds, 'how the crystals were formed in the helmet, and on the adhering calcareous deposit. There being no reason to suppose deposition from solution, are we not under the necessity of inferring, that the mineralising process depends on a small motion and separation of the particles of the original compound? This motion may have been due to the operation of electro-chemical powers which may have separated the different metals of the alloy.'*

* Phil. Trans., 1826, part ii. p. 55.

Millions of silver dollars and other coins have been sometimes submerged in a single ship, and on these, when they happen to be enveloped in a matrix capable of protecting them from chemical changes, much information of historical interest will remain inscribed, and endure for periods as indefinite as have the delicate markings of zoophytes or lapidified plants in some of the ancient paleozoic rocks. In almost every large ship, moreover, there are some precious stones set in seals, and other articles of use and ornament composed of the hardest substances in nature, on which letters and various images are carved—engravings which they may retain when included in subaqueous strata, as long as a crystal preserves its natural form.

It was, therefore, a splendid boast, that the deeds of the English chivalry at Agincourt made Henry's chronicle

> ——as rich with praise
> As is the ooze and bottom of the deep
> With sunken wreck and sumless treasuries;

for it is probable that a greater number of monuments of the skill and industry of man will, in the course of ages, be collected together in the bed of the ocean, than will exist at any one time on the surface of the continents.

CITIES AND FORESTS SUBMERGED BY THE SUBSIDENCE OF LAND.

Examples of the sinking down of buildings, and portions of towns near the shore, to various depths beneath the level of the sea during subterranean movements, were enumerated in the first volume, Chapter XXIV. The events alluded to were comprised within a brief portion of the historical period, and confined to a small number of the regions of active volcanos. Yet these authentic facts, relating merely to the last century and a half, gave indications of considerable changes in the physical geography of the globe, and we are not to suppose that these were the only spots throughout the surrounding land and sea which suffered similar depressions.

If, during the short period since South America has been

colonised by Europeans, we have proof of alterations of level at the three principal ports on the western shores, Callao, Valparaiso, and Conception,* we cannot for a moment suspect that these cities, so distant from each other, have been selected as the peculiar points where the desolating power of the earthquake has expended its chief fury. On considering how small is the area occupied by the seaports of this disturbed region—points where alone each slight change of the relative level of the sea and land can be recognised,—and reflecting on the proofs in our possession of the local revolutions that have happened on the site of each port, within the last century and a half,—our conceptions must be greatly exalted respecting the magnitude of the alterations which the country between the Andes and the sea may have undergone, even in the course of the last six thousand years.

Cutch earthquake.—The manner in which a large extent of surface may be submerged, so that the terrestrial plants and animals may be imbedded in subaqueous strata, cannot be better illustrated than by the earthquake of Cutch, in 1819, before alluded to (p. 97). It is stated that for some years after that earthquake, the withered tamarisks and other shrubs protruded their tops above the waves, in parts of the lagoon formed by subsidence, on the site of the village of Sindree and its environs; but after the flood of 1826, they were seen no longer. Every geologist will at once perceive that forests sunk by such subterranean movements may become imbedded in subaqueous deposits, both fluviatile and marine, and the trees may still remain erect, or sometimes the roots and part of the trunks may continue in their original position, while the current may have broken off, or levelled with the ground, their upper stems and branches.

Buildings how preserved under water.—Some of the buildings which have at different times subsided beneath the level of the sea have been immediately covered up to a certain extent with strata of volcanic matter showered down upon them. Such was the case at Tomboro in Sumbawa, in the present century, and on the site of the Temple of Serapis, in the

* See above, pp. 90, 94, 154, 156.

environs of Puzzuoli, probably about the 12th century. The entrance of a river charged with sediment in the vicinity may still more frequently occasion the rapid envelopment of buildings in regularly stratified formations. But, if no foreign matter be introduced, the buildings, when once removed to a depth where the action of the waves is insensible, and where no great current happens to flow, may last for indefinite periods, and be as durable as the floor of the ocean itself, which may often be composed of the very same materials. There is no reason to doubt the tradition mentioned by the classic writers, that the submerged Grecian towns of Bura and Helice were seen under water; and ruins of old submerged towns are mentioned by Captain Spratt as being visible in the sea off the eastern extremity of Crete or Candia. It has been already mentioned that different eye-witnesses have observed the houses of Port Royal, at the bottom of the sea, at intervals of 88, 101, and 143 years after the convulsion of 1692 (p. 160).

Buried temples of Cashmere. — The celebrated valley of Cashmere (or Kashmir) in India, situated at the southern foot of the Himalaya range, is about 60 miles in length, and 20 in breadth, surrounded by mountains which rise abruptly from the plain to the height of about 5,000 feet. In the cliffs of the river Jelam and its tributaries, which traverse this beautiful valley, strata consisting of fine clay, sand, soft sandstone, pebbles, and conglomerate are exposed to view. They contain freshwater shells, of the genera Lymneus, Paludina, and Cyrena, with landshells, all of recent species, and are precisely such deposits as would be formed if the whole valley were now converted into a great lake, and if the numerous rivers and torrents descending from the surrounding mountains were allowed sufficient time to fill up the lake-basin with fine sediment and gravel. Fragments of pottery met with at the depth of 40 and 50 feet in this lacustrine formation show that the upper part of it at least has accumulated within the human epoch.

Dr. Thomas Thomson, who visited Cashmere in 1848, observes that several of the lakes which still exist in the great valley, such as that near the town of Cashmere, five miles in

diameter, and some others, are deeper than the adjoining river-channels, and may have been formed by subsidence during the numerous earthquakes which have convulsed that region in the course of the last 2,000 years. It is also probable that the freshwater strata seen to extend far and wide over the whole of Cashmere originated not in one continuous sheet of water once occupying the entire valley, but in many lakes of limited area, formed and filled in succession. Among other proofs of such lake-basins of moderate dimensions having once existed and having been converted into land at different periods, Dr. Thomson mentions that the ruins of Avantipura, not far from the modern village of that name, stand on an older freshwater deposit at the base of the mountains, and terminate abruptly towards the plain in a straight line, such as admits of no other explanation than by supposing that the advance of the town in that direction was arrested by a lake, now drained or represented only by a marsh. In that neighbourhood, as very generally throughout Cashmere, the rivers run in channels or alluvial flats, bounded by cliffs of lacustrine strata, horizontally stratified, and these strata form low table-lands from 20 to 50 feet high between the different watercourses. On a table-land of this kind near Avantipura, portions of two buried temples are seen, which have been partially explored by Major Cunningham, who, in 1847, discovered that in one of the buildings a magnificent colonnade of seventy-four pillars is preserved underground. He exposed to view three of the pillars in a cavity still open. All the architectural decorations below the level of the soil are as perfect and fresh-looking as when first executed. The spacious quadrangle must have been silted up gradually at first, for some unsightly alterations, not in accordance with the general plan and style of architecture, were detected, evidently of subsequent date, and such as could only have been required when the water and sediment had already gained a certain height in the interior of the temple.

This edifice is supposed to have been erected about the year 850 of our era, and was certainly submerged before the year 1416, when the Mahomedan king, Sikandar, called Butshikan or the idol-breaker, destroyed all the images of Hindoo

temples in Cashmere. Ferishta, the historian, particularly alludes to Sikandar having demolished every Cashmerian temple save one, dedicated to Mahadéva, which escaped 'in consequence of its foundations being below the neighbouring water.' The unarmed condition of the human-headed birds and other images in the buried edifice near Avantipura leaves no doubt that they escaped the fury of the iconoclast by being under water, and perhaps silted up before the date of his conquest.*

MODERN ORIGIN OF MAN AS INFERRED FROM GEOLOGICAL EVIDENCE.

Bishop Berkeley on the recent date of the creation of man.—Bishop Berkeley, in a memorable passage written more than a century ago, inferred, on grounds which may be termed strictly geological, the recent date of the creation of man. 'To anyone,' says he, 'who considers that on digging into the earth, such quantities of shells, and in some places, bones and horns of animals, are found sound and entire, after having lain there in all probability some thousands of years, it should seem probable that guns, medals, and implements in metal or stone might have lasted entire, buried underground forty or fifty thousand years, if the world had been so old. How comes it then to pass that no remains are found, no antiquities of those numerous ages preceding the Scripture accounts of time; that no fragments of buildings, no public monuments, no intaglios, cameos, statues, basso-relievos, medals, inscriptions, utensils, or artificial works of any kind, are ever discovered, which may bear testimony to the existence of those mighty empires, those successions of monarchs, heroes, and demi-gods, for so many thousand years? Let us look forward and suppose ten or twenty thousand years to come, during which time we will suppose that plagues, famine, wars, and *earthquakes* shall have made great havoc in the world, is it not highly probable that at the end of such a period, pillars, vases, and statues now in being of granite, or

* Thomson's Western Himalaya and Thibet, p. 292. London, 1852. Cunningham, vol. xvii. Journ. Asiat. Soc. Bengal, pp. 241, 277.

porphyry, or jasper (stones of such hardness as we know them to have lasted 2,000 years above ground, without any considerable alteration), would bear record of these and past ages? Or that some of our current coins might then be dug up, or old walls and the foundations of buildings show themselves, as well as the shells and stones of *the primeval world,* which are preserved down to our times?' *

We may with confidence anticipate, like Berkeley, that if the duration of the planet is indefinitely protracted, many edifices and implements of human workmanship and the skeletons of men will be entombed in freshwater, marine, and volcanic strata, and will continue to exist even when a great part of the present mountains, continents, and seas shall have disappeared. The earth's crust must be remodelled more than once before all the memorials of man which are continually becoming entombed in the rocks now forming will be destroyed. *One* complete revolution will be inadequate to efface every monument of our existence; for many works of art might enter again and again into the formations of successive eras, and escape obliteration, even though the very rocks in which they had been for ages imbedded were destroyed, just as pebbles included in the conglomerates of one epoch often contain the organised remains of beings which flourished during a prior era.

Yet it is no less true, as a late distinguished philosopher has declared, 'that none of the works of a mortal being can be eternal.' They are in the first place wrested from the hands of man and lost, so far as regards their subserviency to his use, by the instrumentality of those very causes which place them in situations where they are enabled to endure for indefinite periods. And even when they have been included in rocky strata, when they have been made to enter as it were into the solid framework of the globe itself, they must nevertheless eventually perish; for every year some portion of the earth's crust is shattered by earthquakes, or melted by volcanic fire, or ground to dust by the moving waters on the surface. 'The river of Lethe,' as Bacon

* Alciphron, or the Minute Philosopher, vol. ii. pp. 84, 85. 1732.

eloquently remarks, 'runneth as well above ground as below.' *

Monuments of pre-historic man in Europe.—The reader will see from what was said in the forty-third chapter, that although we might expect man to become cosmopolitan as soon as he had acquired such intellectual superiority as belongs even to the lowest of the human races now inhabiting the globe, yet so long as he was slightly inferior to these races, he may have continued for an indefinite time restricted to one limited area, like the living species of anthropomorphous mammalia. Even if he existed as a rational being before the close of the Pliocene period, we have no right to assume in the present state of science that we should have obtained geological evidence of his existence. When treating of the changes of climate in the first volume I gave some account (p. 174) of the results of the joint investigations of the geologist and archæologist in regard to the remains of pre-historic man. It will there be seen that all these remains belong to the latter part of that modern period in geology which I have called Post-Tertiary, when all the shells, marine and freshwater, were already of the same species as those now living.

The age of Iron was preceded in Europe by that of Bronze, when tools of that mixed metal were in use. These bronze weapons prevailed in Switzerland and Gaul long before the Roman invasion of those countries. Implements of the same mixture of copper and tin occur in many of the Swiss lake-villages and in the peat-mosses of Great Britain, Ireland, and Scandinavia. But coins are entirely absent, and no proofs of the art of writing or of letters having been invented have yet been brought to light. Some of the pottery of the Bronze age is said to show marks of the potter's wheel, but the greater part of it was made by hand. Professor Nilsson long ago observed that the handles of the swords as well as the bracelets of the Bronze age indicate that the size of the race which used them was smaller than that of the present inhabitants of Northern Europe. Many animals had been domes-

* Essay on the Vicissitude of Things.

ticated by man in this period, as is shown by the bones preserved in certain Swiss lake-dwellings; several cereals also and fruits were cultivated. Gold, amber, and glass were in use for ornamental purposes, but there is no evidence that silver, zinc, and lead were known. In the Swiss lake-villages of the antecedent Stone period called Neolithic, as being newer than a still older age of stone, men were evidently ignorant of the art of metallurgy. Polished axes commonly called celts, chisels, and other tools, were so abundant in Northern and Western Europe that the Dublin Museum contains more than 2,000 of them, that of Copenhagen more than 10,000, and that of Stockholm not fewer than 15,000.*

The Danish shell-mounds or kitchen-middens, as well as many of the Swiss lake-dwellings, and a large part of the European peat, belong to this Neolithic period, but none of the polished implements of this age occur in the river-drift gravel-beds, nor in association with extinct mammalia. Hand-made pottery was in use; the ox, sheep, goat, pig, and dog were already domesticated, agriculture had commenced, and flax was cultivated and woven into tissues.

Next in our retrospective survey we come to the monuments of what M. Lartet has called the Rein-deer period, when that animal abounded in the south of France.

To this era belong the caves of the Dordogne in central France, in which MM. Lartet, Christy, and others have obtained thousands of implements made out of stone, bone, and horn without a trace of any associated pottery, still less of metallic tools, or polished stone implements. M. Lartet found in one cave of this period at La Madeleine a fragment of mammoth tusk on which was rudely carved a representation of the animal itself; a fact which seems to prove that this species coexisted with these cave-men. Traces also of the musk-ox and cave-lion have been met with in the same caves, but some doubts are still entertained whether these quadrupeds were contemporary with the men of the Rein-deer period. This period may be considered as intermediate

* Sir J. Lubbock, Introduction to Translation of Nilsson's 'Primitive Inhabitants of Scandinavia,' p. xxiv.

between the Neolithic and Palæolithic ages, but it has been classed provisionally by Sir J. Lubbock as Palæolithic. The climate then prevailing in the south of Europe was evidently much colder than it is now, but the state of physical geography has not since undergone any material alteration.

Lastly we arrive at the still older monuments of the Palæolithic period properly so called, which consist chiefly of unpolished stone implements buried in ancient river-gravels and in the mud and stalagmite of caves. Both the gravel and the caves are now so situated in their relation to the present drainage and geography of the countries where they occur as to imply a great lapse of intervening time during which the erosive power of rivers has been active in deepening the valleys. The implements of this age in Western Europe are chiefly composed of chalk-flint—more rarely of chert from the greensand. Besides being unpolished they differ in shape from those of the Neolithic age.* They are associated with remains of the mammoth, the woolly-haired rhinoceros, the hippopotamus, the musk-ox, and many other quadrupeds of extinct and living species. No pottery has been found strictly referable to this era, and there is an entire absence of metallic weapons, as in the later Bronze period of coins.

The beds of gravel often called drift, which contain antiquities of this age, may be said to have been deposited by the existing rivers, when these ran in the same direction as at present, and drained the same areas, but before the valleys had been scooped out to their present depth. The height above the present alluvial plains at which the old drift occurs is often no more than 20 or 30 feet, but sometimes 100 or even 200 feet. Flint flakes having a fine cutting edge, evidently chipped off by the hand of man, are met with not only in the old drift, but in formations of the Neolithic and Bronze ages, for they afford the finest cutting edge that was obtainable before the invention of steel. In the caves of this early Stone period implements of the same antique type, with fossil skeletons of man, have been detected, agreeing, as before hinted

* See Lyell's 'Antiquity of Man,' pp. 114 and 118, and Lubbock's 'Pre-historic Times.'

(p. 493), in osteological character with some of the existing races of man. It has been estimated that the number of flint implements of the Palæolithic type already found in northern France and southern England, exclusive of flakes, is not less than 3,000.* No similar tools have been met with in Denmark, Sweden, or Norway, where Nilsson, Thomsen, and other antiquaries have collected with so much care the relics of the Stone age. Hence it is supposed that Palæolithic man never penetrated into Scandinavia, which may perhaps have been as much covered with ice and snow as the greater part of Greenland is at present.

Palæolithic implements in the drift of the south of Hampshire.—Flint implements of the normal type of the Palæolithic period have been lately found in the south of Hampshire, not in caves nor in old river-gravels within the limits of existing valleys, but in a tabular mass of drift which caps the Tertiary strata, and which is intersected both by the Solent and by the valleys of all the rivers which flow into that channel of the sea. The position of these implements, to which the archæologists of Salisbury have called our attention, attests perhaps in a more striking manner the antiquity of prehistoric man in Europe than any other monument of the earlier Stone age yet discovered. The great bed of gravel resting on Eocene Tertiary strata in which these implements have been found, consists in most places of half-rolled or semi-angular chalk-flints, mixed with rounded pebbles washed out of the Tertiary strata. But this drift, although often continuous over wide areas, is not everywhere present, nor does it always present the same characters. The first flint implements found in it were discovered mid-way between Gosport and Southampton, by Mr. James Brown of Salisbury, in May 1864, included in gravel from 8 to 12 feet thick, capping a cliff which at its greatest height is 35 feet above high-water mark. I have visited this spot, which had previously been seen by Messrs. Prestwich and Evans. The flint-tools exactly resemble those found at Abbeville and Amiens in France, being some of them of the oval, and others of the lanceo-

* Sir J. Lubbock, Introduction to Nilsson's 'Primitive Inhabitants of Scandinavia,' p. xx.

late form. Many of them exhibit the same colours and ochreous stain as do the flints in the gravel in which they lay. A fine series of these implements, from the Hampshire cliffs, may now be seen in the Blackmore Museum at Salisbury.

In the gravel capping the cliffs alluded to are blocks of sandstone of various sizes, some of enormous dimensions, more than 20 feet in circumference and from 1 to 2½ feet thick. They have probably not travelled far, being a portion of the wreck of the Eocene strata which have suffered much denudation. Nevertheless to explain how they and the stone implements became enveloped in the débris of chalk-flints, we must have recourse to ice, which may have been frozen on to them in winter, so as to give them buoyancy and enable rivers or the sea to transport them to slight distances from their original site. An extreme climate, causing a vast accumulation of snow during a cold winter, and great annual floods when this snow was suddenly melted in the beginning of the warm season, may best account for the destruction of large masses of chalk in the upland country, and the spreading over the ancient surface of the flinty material originally dispersed in layers through the soft chalk. The occasional occurrence of unrolled chalk-flints in the gravel in places where they must have travelled twelve miles from their nearest source, also implies the aid of ice-action. The transverse valleys now intersecting the region near the coast where the flint tools are found, near Gosport, must have been cut through the Tertiary strata, after the over-lying gravel had been superimposed, for this last forms a flat table-land between the valleys.

On the whole we may infer that not only the valleys of the smaller streams near Gosport, but those of the Test (or Southampton river) and of the stream which enters at Lymington, and those of the rivers Avon and Stour, which reach the Solent at Christchurch, as well as the Bournemouth valley, have all been excavated since Palæolithic man inhabited this region; for not only at various points east of the Southampton estuary, but west of it also on both sides of the opening at Bournemouth, flint tools of the ancient type have been met with in the gravel capping the cliffs. The gravel from which

the flint tool was taken at Bournemouth is about 100 feet above the level of the sea; as I ascertained after examining the spot in 1867.*

The gravel consists in great part of pebbles derived from Tertiary strata; and if it was originally spread out by rivers, the course of the drainage must since have been altered to such an extent that it is not easy to trace any connection between the old watercourses and those of the existing valleys.

I learn from Mr. Evans that Mr. Thomas Codrington discovered in 1868 an oval flint implement in gravel at the top of the Foreland cliff on the most eastern point of the Isle of Wight, five miles south-east of Ryde. It is of the true Palæolithic type, and the gravel in which it is imbedded at the height of about 80 feet above the level of the sea, may, as Mr. Evans suggests, have once extended to the cliffs near Gosport; in which case we should have to infer that the channel called the Solent had not yet been scooped out when this region was inhabited by Palæolithic man. The gravel found at Freshwater at the west end of the Isle of Wight, in which the remains of the mammoth have been detected, is probably of the same date.

If we ascend the Avon from Christchurch to Salisbury about 30 miles to the north, we find in gravels at various heights about the river, and in old fluviatile alluvium, flint tools of the same Palæolithic type. One of these was taken out by Dr. Blackmore from beneath the remains of a mammoth, at Fisherton, near Salisbury. The remains of no less than 21 species of mammalia have also been detected at the same place, the greatest number, perhaps, obtained in any one spot in Great Britain. The associated land and freshwater shells belong to 31 species, and are all still living in England, although the quadrupeds imply a colder climate. Among these are the mammoth and woolly-haired rhinoceros, the rein-deer, and Norwegian lemming, the Greenland lemming,

* Mr. Alfred Stevens first dug out a hatchet (April 1866) from this gravel at the top of the sea-cliff east of the Bournemouth opening. Dr. Blackmore soon afterwards obtained two other similar implements from gravel west of the Bournemouth valley.

and another species of the same family, the Spermophilus, allied to the marmot. Of this last 13 individuals have been found, some of the skeletons being perfect, and lying, as remarked by Dr. Blackmore, in the curved attitude of hibernation, as may now be seen in the Blackmore Museum. Besides the bones of quadrupeds, the femur and coracoid bones of the wild goose (*Anser palustris*) have been met with, and some egg-shells corresponding in size with the eggs of the wild goose and wild duck. These shells are in part covered with superficial incrustations. As the wild goose now resorts to arctic regions in the breeding season, the occurrence of its eggs at Fisherton seems to imply a cold climate such as would have suited the lemming and marmot.*

To conclude, there are three independent classes of evidence, which in this part of Hampshire point distinctly to the vast antiquity of Palæolithic man. First, the great denudation of the Chalk and Tertiary strata, and the important changes in the shape and depth of the valleys and the contour of the sea-coast which have since occurred in Hampshire; secondly, a marked change in the fauna, by the dying out of so many conspicuous species of quadrupeds; and thirdly, the change of climate from a colder to a warmer temperature, implied by the former presence of northern animals, and by the ice-borne erratics of the drift.

Age of pottery buried in upraised marine strata in Sardinia.—I have elsewhere called attention † to a marine formation described by Count Albert de la Marmora as occurring at Cagliari, on the southern coast of the island of Sardinia, at the height of more than 300 feet above the level of the Mediterranean. In this deposit some rude fragments of pottery were found together with a flattened ball of baked earthenware, with a hole through the axis, supposed to have been used for weighting fishing-nets. These works of art were associated with marine shells all of living species, the oysters and mussels having both valves united together. I

* Evans, Geol. Quart. Journ., p. 193, Aug. 1864.

† See 'Antiquity of Man,' p. 177.

know of no other instance in Europe of a sea-bottom of the human period having been lifted up 300 feet above its former level; but in countries like Sardinia, where the latest volcanic cones are of Newer Pliocene, if not of Post-Pliocene date, such an upheaval may not imply a greater antiquity than may belong to Neolithic times.

CHAPTER XLVIII.

IMBEDDING OF AQUATIC SPECIES IN SUBAQUEOUS STRATA.

INHUMATION OF FRESHWATER PLANTS AND ANIMALS—SHELL-MARL—FOSSILISED SEED-VESSELS AND STEMS OF CHARA—RECENT DEPOSITS IN AMERICAN LAKES—FRESHWATER SPECIES DRIFTED INTO SEAS AND ESTUARIES—LEWES LEVELS—ALTERNATIONS OF MARINE AND FRESHWATER STRATA, HOW CAUSED—IMBEDDING OF MARINE PLANTS AND ANIMALS—CETACEA STRANDED ON OUR SHORES—LITTORAL AND ESTUARY TESTACEA SWEPT INTO THE DEEP SEA—BURROWING SHELLS—LIVING TESTACEA FOUND AT CONSIDERABLE DEPTHS—BLENDING OF ORGANIC REMAINS OF DIFFERENT AGES.

Having treated of the imbedding of terrestrial plants and animals, and of human remains, in deposits now forming beneath the waters, I come next to consider in what manner *aquatic* species may be entombed in strata formed in their own element.

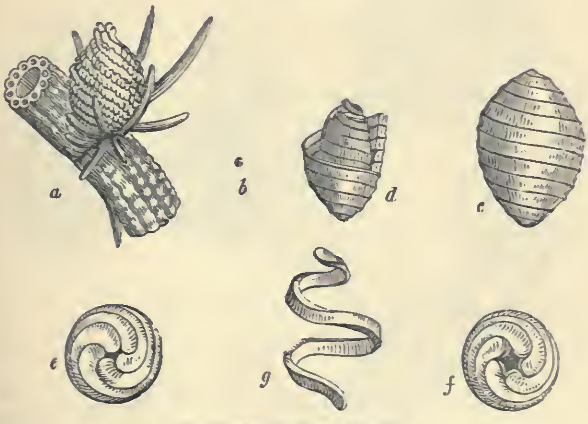
Freshwater plants and animals.—The remains of species belonging to those genera of the animal and vegetable kingdoms which are more or less exclusively confined to fresh water are for the most part preserved in the beds of lakes or estuaries, but they are oftentimes swept down by rivers into the sea, and there intermingled with the exuviæ of marine races. The phenomena attending their inhumation in lacustrine deposits are sometimes revealed to our observation by the drainage of small lakes, such as are those in Scotland, which have been laid dry for the sake of obtaining shell-marl for agricultural uses.

In these modern formations, as seen in Forfarshire, two or three beds of calcareous marl are sometimes observed separated from each other by layers of drift peat, sand, or fissile clay. The marl often consists almost entirely of an aggregate of shells of the genera Limnea, Planorbis, Valvata, and Cyclas, of species now existing in Scotland. A considerable proportion of the Testacea appear to have died very young, and

few of the shells are of a size which indicates their having attained a state of maturity. The shells are sometimes entirely decomposed, forming a pulverulent marl; sometimes in a state of good preservation. They are frequently intermixed with stems of Charæ and other aquatic vegetables, the whole being matted together and compressed, forming laminæ often as thin as paper.

As the Chara is an aquatic plant which occurs frequently fossil in formations of different eras, and is often of much importance to the geologist in characterising entire groups of strata, I shall describe the manner in which I have found the recent species in a petrified state. They occur in a marl-lake in Forfarshire, enclosed in nodules, and sometimes in a continuous stratum of a kind of travertin.

Fig. 146.



Seed-vessel of *Chara hispida*.

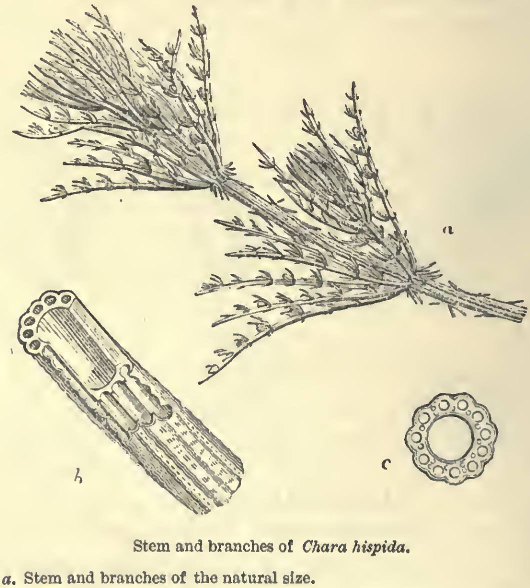
a. Part of the stem with the seed-vessel attached. Magnified.
b. Natural size of the seed-vessel.
c. Integument of the Gyrogonite, or petrified seed-vessel of *Chara hispida*, found in the Scotch marl-lakes. Magnified.
d. Section showing the nut within the integument.
e. Lower end of the integument to which the stem was attached.
f. Upper end of the integument to which the stigmata were attached.
g. One of the spiral valves of *c*.

The seed-vessel of these plants is remarkably tough and hard, and consists of a membranous nut covered by an integument (*d*, fig. 146), both of which are spirally striated or ribbed. The integument is composed of five spiral valves, of

a quadrangular form (*g*). In *Chara hispida*, which abounds in a living state in the lakes of Forfarshire, and which has become fossil in the Bakie Loch, each of the spiral valves of the seed-vessel turns rather more than twice round the circumference, the whole together making between ten and eleven rings. The number of these rings differs greatly in different species, but in the same appears to be very constant.

The stems of Charæ occur fossil in the Scotch marl in great abundance. In some species, as in *Chara hispida*, the plant when living contains so much carbonate of lime in its vegetable organisation, independently of calcareous incrustation, that it effervesces strongly with acids when dry.

Fig. 147.



Stem and branches of *Chara hispida*.

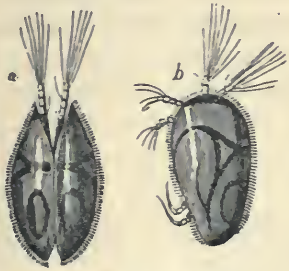
a. Stem and branches of the natural size.
b. Section of the stem magnified.
c. Showing the central tube surrounded by two rings of smaller tubes.

The longitudinal striæ on the stems of *Chara hispida* have a tendency to be spiral, and as appears to be the case with other species of the genus, turn always like the worm of a screw, so that the spiral valves as seen on the outside turn from right to left, while those of the seed-vessel wind round in a contrary direction. A cross section of the stem

exhibits a curious structure, for it is composed of a large tube surrounded by smaller tubes (fig. 147, *b*, *c*), as is seen in some extinct as well as recent species. In the stems of several species, however, there is only a single tube.*

The valves of a small animal called Cypris (*C. ornata* ? Lam.) occur completely fossilised, like the stems of Chara, in the Scotch travertin above mentioned. The same Cypris inhabits the lakes and ponds of England, where, together with many other species, it is not uncommon. Although extremely minute, they are visible to the naked eye, and may be observed in great numbers, swimming swiftly through the waters of our stagnant pools and ditches. The antennæ, at the end of which are fine pencils of hair, are the principal organs for swimming, and are moved with great rapidity. The animal

Fig. 148.



Cypris unifasciata, a living species, greatly magnified.

a. Upper part. *b.* Side view of the same.

Fig. 149.

Cypris vidua, a living species, greatly magnified.†

resides within two small valves, not unlike those of a bivalve mollusk, and moults its integuments annually, which the conchiferous mollusk does not. The cast-off shells, resembling thin scales, and occurring in countless myriads in many ancient freshwater marls, impart to them a divisional structure, like that so frequently derived from plates of mica.

The recent strata of lacustrine origin above alluded to are of very small extent, but analogous deposits on the grandest scale are forming in the great Canadian lakes, as in Lakes

* On Freshwater Marl, &c. By C. Lyell, Geol. Trans., vol. ii., second series, p. 73.

† See Desmaret's Crustacea, pl. 55.

Superior and Huron, where beds of sand and clay are seen enclosing shells of existing species.* In Lake Superior during the late dredgings (August 1871) the greatest depth ascertained was 1,014 feet, and the temperature of the water everywhere below 40 fathoms (240 feet) was almost constant at 39° F., which is evidently connected with its maximum density. At the surface at the same time it was found to range from 50° to 55° F. In the shallow water the fauna varied with the character of the bottom, while the deep-water fauna, composed of small mollusks and crustaceans, was meagre, and like the temperature seemed to be everywhere very uniform.† The Charæ also play the same part in the subaqueous vegetation of North America as in Europe. I observed along the borders of several freshwater lakes in the State of New York a luxuriant crop of this plant in clear water of moderate depth, rendering the bottom as verdant as a grassy meadow. Here, therefore, we may expect some of the tough seed-vessels to be preserved in mud, just as we detect them fossil in the Eocene strata of Hampshire, or in the neighbourhood of Paris, and in many other countries.

IMBEDDING OF FRESHWATER SPECIES IN ESTUARY AND MARINE DEPOSITS.

We have sometimes an opportunity of examining the deposits which within the historical period have silted up some of our estuaries; and excavations made for wells and other purposes, where the sea has been finally excluded, enable us to observe the state of the organic remains in these tracts. The valley of the Ouse between Newhaven and Lewes is one of several estuaries from which the sea has retired within the last seven or eight centuries; and here, as appears from the researches of Dr. Mantell, strata 30 feet and upwards in thickness have accumulated. At the top, beneath the vegetable soil, is a bed of peat about 5 feet thick, enclosing many trunks of trees. Next below is a stratum of blue clay con-

* Dr. Bigsby, Journn. of Science, &c., No. xxxvii. pp. 262, 263.

† Silliman's Journal, vol. ii. p. 373, Nov. 1871.

taining freshwater shells of about nine species, such as now inhabit the district. Intermixed with these was observed the skeleton of a deer. Lower down, the layers of blue clay contain, with the above-mentioned freshwater shells, several marine species well known on our coast. In the lowest beds, often at the depth of 36 feet, these marine Testacea occur without the slightest intermixture of fluviatile species, and amongst them the skull of a narwal, or sea-unicorn (*Monodon monoceros*), has been detected. Underneath all these deposits is a bed of pipe-clay, derived from the subjacent chalk.*

If we had no historical information respecting the former existence of an inlet of the sea in this valley and of its gradual obliteration, the inspection of the section above described would show, as clearly as a written chronicle, the following sequence of events. First, there was a salt-water estuary peopled for many years by species of marine Testacea identical with those now living, and into which some of the larger Cetacea occasionally entered. Secondly, the inlet grew shallower, and the water became brackish, or alternately salt and fresh, so that the remains of freshwater and marine shells were mingled in the blue argillaceous sediment of its bottom. Thirdly, the shoaling continued until the river-water prevailed, so that it was no longer habitable by marine Testacea, but fitted only for the abode of fluviatile species and aquatic insects. Fourthly, a peaty swamp or morass was formed, where some trees grew, or perhaps were drifted during floods, and where terrestrial quadrupeds were mired. Finally, the soil being flooded by the river only at distant intervals, became a verdant meadow.

It was before stated, that on the sea-coast, in the delta of the Ganges, there are eight great openings, each of which has evidently, at some ancient period, served in its turn as the principal channel of discharge.† As the base of the delta is 200 miles in length, it must happen that, as often as the great volume of river-water is thrown into the sea by a new mouth, the sea will at one point be converted from salt to fresh, and at another from fresh to salt; for, with the excep-

* Mantell, Geol. of Sussex, p. 285; also Catalogue of Org. Rem., Geol. Trans, vol. iii. part i. p. 201, 2nd series.

† Vol. i. p. 469.

tion of those parts where the principal discharge takes place, the salt water not only washes the base of the delta, but enters far into every creek and lagoon. It is evident, then, that repeated alternations of beds containing freshwater shells, with others filled with marine exuviæ, may here be formed. It has also been shown by artesian borings at Calcutta (see Vol. I. p. 476) that the delta once extended much farther than now into the gulf, and that the river is only recovering from the sea the ground which had been lost by subsidence at some former period. Analogous phenomena must sometimes be occasioned by such alternate elevation and depression as have occurred in modern times in the delta of the Indus.* But the subterranean movements affect a small number only of the deltas formed at one period on the globe; whereas the silting up of some of the arms of great rivers, and the opening of others, and the consequent variation of the points where the chief volume of their waters is discharged into the sea, are phenomena common to almost every delta.

The variety of species of Testacea contained in the recent calcareous marl of Scotland, before mentioned, is very small, but the abundance of individuals extremely great, a circumstance very characteristic of freshwater and brackish formations in general, as compared to marine; for in the latter, as is seen on sea-beaches, coral-reefs, or in the bottom of seas examined by dredging, wherever the individual shells are exceedingly numerous, there rarely fails to be a vast variety of species.

IMBEDDING OF THE REMAINS OF MARINE PLANTS AND ANIMALS.

Marine plants.—The large banks of drift sea-weed which occur on each side of the equator in the Atlantic, Pacific, and Indian oceans, were before alluded to.† These, when they subside, may often produce considerable beds of vegetable matter. In Holland, sub-marine peat is derived from Fuci, and on parts of our own coast from sea-wrack (*Zostera marina*).

* Page 99. † Page 395.

In places where Algæ do not generate peat, they may nevertheless leave traces of their form imprinted on argillaceous and calcareous mud, as they are usually very tough in their texture.

Sea-weeds are often cast up in such abundance on our shores during heavy gales, that we cannot doubt that occasionally vast numbers of them are imbedded in littoral deposits now in progress. We learn from the researches of Dr. Forchhammer, that besides supplying in common with land-plants the materials of coal, the Algæ must give rise to important chemical changes in the composition of strata in which they are imbedded. These plants always contain sulphuric acid, and sometimes in as large a quantity as 8½ per cent., combined with potash: magnesia also and phosphoric acid are constant ingredients. Whenever large masses of sea-weeds putrefy in contact with ferruginous clay, sulphuret of iron, or iron pyrites, is formed by the union of the sulphur of the plants with the iron of the clay. Many of the mineral characteristics of ancient rocks, especially the alum slates, and the pyrites which occur in clay slate, and the fragments of anthracite in marine strata, may be explained by the decomposition of fucoids or sea-weeds.*

Imbedding of cetacea.—It is not uncommon for the larger Cetacea, which can float only in a considerable depth of water, to be carried during storms or high tides into estuaries, or upon low shores, where, upon the retiring of high water, they are stranded. Thus a narwal (*Monodon monoceros*) was found on the beach near Boston in Lincolnshire, in the year 1800, the whole of its body buried in the mud. A fisherman going to his boat saw the horn, and tried to pull it out, when the animal began to stir itself.† An individual of the common whale (*Balæna mysticetus*), which measured 70 feet, came ashore near Peterhead, in 1682. Many individuals of the genus Balænoptera have met the same fate. It will be sufficient to refer to those cast on shore in the Firth of Forth near Burntisland, and at Alloa, recorded by Sibbald and Neill. The other individual

* Forchhammer, Report British Assoc. 1844.

† Fleming's Brit. Animals, p. 37; in which work other cases are enumerated.

mentioned by Sibbald, as having come ashore at Boyne, in Banffshire, was probably a razor-back. Of the genus Catodon (*Cachalot*), Ray mentions a large one stranded on the west coast of Holland in 1598, and the fact is also commemorated in a Dutch engraving of the time of much merit. Sibbald, too, records that a herd of Cachalots, upwards of 100 in number, were found stranded at Cairston, in Orkney. The dead bodies of the larger Cetacea are sometimes found floating on the surface of the waters, as was the case with the immense whale exhibited in London in 1831. And the carcass of a sea-cow or Lamantine (*Halicora*) was, in 1785, cast ashore near Leith.

To some accident of this kind we may refer the position of the skeleton of a whale, 73 feet long, which was found at Airthie, on the Forth, near Stirling, imbedded in clay 20 feet higher than the surface of the highest tide of the river Forth at the present day. From the situation of the Roman station and causeways at a small distance from the spot, it is concluded that the whale must have been stranded there at a period prior to the Christian era.*

Marine reptiles.—Some singular fossils have been discovered in the Island of Ascension in a stone said to be continually forming on the beach, where the waves throw up small rounded fragments of shells and corals, which, in the course of time, become firmly agglutinated together, and constitute a stone used largely for building and making lime. In a quarry on the N.W. side of the island, about 100 yards from the sea, some fossil eggs of turtles have been discovered in the hard rock thus formed. The eggs must have been nearly hatched at the time when they perished; for the bones of the young turtle are seen in the interior, with their shape fully developed, the interstices between the bones being entirely filled with grains of sand, which are cemented together, so

Fig. 150.

Fossil eggs of turtles from the Island of Ascension.†

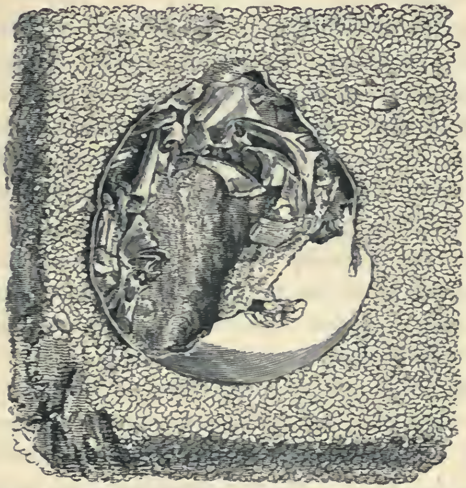
* Quart. Journ. of Lit. Sci., &c., No. xv. p. 172. Oct. 1819.

† This specimen has been presented by Mr. Lonsdale to the Geological Society of London.

that when the egg-shells are removed perfect casts of their form remain in stone. In the single specimen here figured (fig. 150), which is only five inches in its longest diameter, no less than seven eggs are preserved.*

To explain the state in which they occur fossil, it seems necessary to suppose that after the eggs were almost hatched in the warm sand, a great wave threw upon them so much more sand as to prevent the rays of the sun from penetrating, so that the yolk was chilled and deprived of vitality. The shells were perhaps slightly broken at the same time, so that

Fig. 151.



One of the eggs in fig. 150, of the natural size, showing the bones of the fœtus which had been nearly hatched.

small grains of sand might gradually be introduced into the interior by water as it percolated through the beach.

Marine testacea.—The aquatic animals and plants which inhabit an estuary are liable, like the trees and land animals which people the alluvial plains of a great river, to be swept from time to time far into the deep; for as a river is per-

* The most conspicuous of the bones represented within the shell in fig. 151, appear to be the clavicle and coracoid bone. They are hollow; and for this reason resemble, at first sight, the bones of birds rather than of reptiles; for the latter have no medullary cavity. Prof. Owen, in order to elucidate this point, dissected for me a very young turtle, and found that the exterior portion only of the bones was ossified, the interior being still filled with cartilage.

petually shifting its course, and undermining a portion of its banks with the forests which cover them, so the marine current alters its direction from time to time, and bears away the banks of sand and mud against which it turns its force. These banks may consist in great measure of shells peculiar to shallow and sometimes brackish water, which may have been accumulating for centuries, until at length they are carried away and spread out along the bottom of the sea, at a depth at which they could not have lived and multiplied. Thus littoral and estuary shells are more frequently liable, even than freshwater species, to be intermixed with the exuviæ of pelagic tribes.

After the storm of February 4, 1831, when several vessels were wrecked in the estuary of the Forth, the current was directed against a bed of oysters with such force, that great heaps of them were thrown *alive* upon the beach, and remained above high-water mark. I collected many of these oysters, as also the common eatable whelks (*Buccinum*), thrown up with them, and observed that, although still living, their shells were worn by the long attrition of sand which had passed over them as they lay in their native bed, and which had evidently not resulted from the mere action of the tempest by which they were cast ashore. From these facts we learn that the union of the two parts of a bivalve shell does not prove that it has not been transported to a distance; and when we find shells worn, and with all their prominent parts rubbed off, they may still have been imbedded where they grew.

Burrowing shells.—It sometimes appears extraordinary, when we observe the violence of the breakers on our coast, and see the strength of the current in removing cliffs, and sweeping out new channels, that many tender and fragile shells should inhabit the sea in the immediate vicinity of this turmoil. But a great number of the bivalve Testacea, and many also of the turbinated univalves, burrow in sand or mud. The Solen and the Cardium, for example, which are usually found in shallow water near the shore, pierce through a soft bottom without injury to their shells; and the Pholas can drill a cavity through mud of considerable

hardness. These and many other shells can sink, when alarmed, with considerable rapidity, often to the depth of several feet, and can also penetrate upwards again to the surface, if a mass of matter be heaped upon them. The hurricane, therefore, may expend its fury in vain, and may sweep away even the upper part of banks of sand or mud, or may roll pebbles over them, and yet these Testacea may remain below secure and uninjured.

Depths at which organic bodies may become fossil.—Captain Vidal ascertained in 1834, by soundings made off Tory Island, on the north coast of Ireland, that Crustacea, Starfish, and Testacea occurred at various depths between 50 and 100 fathoms; and he drew up Dentalia from the mud of Galway Bay, in 230 and 240 *fathoms* water. The same hydrographer discovered on the Rockhall Bank large quantities of shells at depths varying from 45 to 190 fathoms. These shells were evidently recent, as they retained their colours. In the same region a bed of fish-bones was observed extending for two miles along the bottom of the sea in 10 and 90 fathoms water. At the eastern extremity also of Rockhall Bank fish-bones were met with, mingled with pieces of fresh shell, at the depth of 235 fathoms.

Analogous formations are in progress in the submarine tracts extending from the Shetland Isles to the north of Ireland, wherever soundings can be procured. A continuous deposit of sand and mud, replete with broken and entire shells, Echini, &c., has been traced for upwards of twenty miles to the eastward of the Faroe Islands, usually at the depth of from 40 to 100 fathoms. In one part of this tract (lat. 61° 50′, long. 6° 30′) fish-bones occur in extraordinary profusion, so that the lead cannot be drawn up without some vertebræ being attached. This 'bone bed,' as it was called by our surveyors, is three miles and a half in length, and forty-five fathoms under water, and contains a few shells intermingled with the bones.

In the British seas, the shells and other organic remains lie in soft mud or loose sand and gravel; whereas, in the bed of the Adriatic, Donati found them frequently enclosed in stone of recent origin. This is precisely the difference in

character which we might have expected to exist between the British marine formations now in progress and those of the Adriatic; for calcareous and other mineral springs abound in the Mediterranean and lands adjoining, while they are almost entirely wanting in our own country.

I have already adverted to the eight regions of different depths in the Ægean Sea, each characterised by a peculiar assemblage of shells, which have been described by Professor E. Forbes, who explored them by dredging (see above, p. 376), and who conjectured from the rate at which the marine fauna grew scantier with the depth, that the zero of animal life would be reached in that sea at about 300 fathoms. This speculation has proved correct in reference to the Mediterranean in general, although mollusca, corals, and bryozoa have since been brought up, adhering to the French telegraph cable between Sardinia and Algiers, from much greater depths.* Messrs. Carpenter and Gwyn Jeffreys, in 1870, examined carefully the mud brought up from the bottom at points below 400 fathoms off the coast of Africa, between Ceuta and Oran, and elsewhere, in the western basin of the Mediterranean, and they found that it consisted of a very fine yellowish sand, mixed with a bluish clay, quite devoid of organic substances, and therefore called by them azoic. This entire absence of life cannot, as they observe, be ascribed simply to the depth, because, as above stated, life has been detected far lower in the Mediterranean. Dr. Carpenter suggests, therefore, that the extremely fine mud brought down by the Rhone,† sinking very gradually to the bottom of the Mediterranean, may be prejudicial to the respiration of various invertebrates, for it is known that oyster-beds cannot be established in situations to which fine mud is brought by any fluvial or tidal current.

In regard to the extreme depth at which life can exist in the ocean, I had already mentioned in my last edition, that Dr. Hooker, in his Antarctic voyage with Captain Sir J. C. Ross, established the fact from soundings made off Victoria Land between lats. 71° and 78° south, that the bottom of the

* Ann. des Sciences, Nat. 4 Series, vol. xv. p. 3.

† See vol. i. p. 423.

ocean was inhabited, at depths of from 200 to 400 fathoms, by crustacea, mollusca, serpulæ, sponges, and other invertebrata,* and Sir Leopold McClintock and Dr. Wallich, in 1860, found living starfish at the depth of a thousand fathoms midway between Greenland and Iceland.

The late deep-sea dredgings carried on in the Atlantic by Messrs. Carpenter, Gwyn Jeffreys, and Wyville Thomson in the 'Porcupine' (1868–71), have still farther extended the downward limit, Professor Wyville Thomson having found life existing in the Bay of Biscay at a depth of 15,000 feet, or as far below the sea level as the summit of Mont Blanc is above it. The sounding alluded to was made in lat. 47° 38′ N., long. 12° 08′ W., about 250 miles west of Ushant, a small island on the north-west coast of France. The dredge brought up in the ooze, mollusca (*Pleurotoma* and *Dentalium*), crustacea, and echinodermata, among which was a crinoid referable to the Apiocrinite type which flourished during the Oolitic period.†

In all such cases, it is only necessary that there should be some deposition of sedimentary matter, however minute, such as may be supplied by rivers draining a continent, or currents preying on a line of cliffs, or melting icebergs loaded with mud, sand, and boulders, in order that stratified formations, hundreds of feet in thickness, and replete with organic remains, should result in the course of ages.

We frequently observe, on the sea-beach, very perfect specimens of fossil shells, quite detached from their matrix, which have been washed out of older formations, constituting the sea-cliffs. They may be all of extinct species, like the Eocene freshwater and marine shells strewed over the southern shores of Hampshire, yet when they become mingled with the shells of the present period, and buried in the same deposits of mud and sand, they might appear, if upraised and examined by future geologists, to have been all of the same age. That such intermixture and blending of organic remains of different ages have actually taken place in former times, is unquestionable, though the occurrence appears to be very local and exceptional. It is, however, a

* 'Antiquity of Man,' p. 268, and Appendix H., p. 528.

† Royal Soc. Proc. vol. xviii. p. 429. 1870.

class of accidents more likely than almost any other to lead to serious anachronisms in geological chronology.

Many have thought that the recent discovery of the coexistence of warm and cold areas within twenty miles of each other, and in the same latitude in the North Atlantic, above alluded to,* would in like manner tend to weaken the value of paleontological evidence as bearing on geological classification. Such fears need not be entertained, for although the current coming from the South and supposed to be connected with the Gulf-stream differed as a whole in its fauna from the Arctic current, the waters of the one containing globigerinæ and vitreous sponges, and those of the other Northern forms of echinodermata and crustacea, yet Mr. Gwyn Jeffreys found that of fifty-five species of mollusca dredged up in the cold area, forty-four were common to the warm area, which possessed no associated peculiar species.† The mollusca, therefore, a class of invertebrata on which geologists are chiefly in the habit of founding their classification, being so many of them common to the two areas, would prevent any serious chronological error in a future comparison of the fossils of the two regions.

* Vol. i. p. 503. † Prestwich Geol. Soc. Add., 1871, p. 47.

CHAPTER XLIX.

FORMATION OF CORAL REEFS.

GROWTH OF CORAL CHIEFLY CONFINED TO TROPICAL REGIONS—PRINCIPAL GENERA OF CORAL-BUILDING ZOOPHYTES—THEIR RATE OF GROWTH—SELDOM FLOURISH AT GREATER DEPTHS THAN TWENTY FATHOMS—ATOLLS OR ANNULAR REEFS WITH LAGOONS—MALDIVE ISLES—ORIGIN OF THE CIRCULAR FORM—CORAL REEFS NOT BASED ON SUBMERGED VOLCANIC CRATERS—MR. DARWIN'S THEORY OF SUBSIDENCE IN EXPLANATION OF ATOLLS, ENCIRCLING AND BARRIER REEFS—WHY THE WINDWARD SIDE OF ATOLLS HIGHEST—SUBSIDENCE EXPLAINS WHY ALL ATOLLS ARE NEARLY ON ONE LEVEL—ALTERNATE AREAS OF ELEVATION AND SUBSIDENCE—ORIGIN OF OPENINGS INTO THE LAGOONS—SIZE OF ATOLLS AND BARRIER REEFS—OBJECTION TO THE THEORY OF SUBSIDENCE CONSIDERED—COMPOSITION, STRUCTURE, AND STRATIFIED ARRANGEMENT OF ROCKS NOW FORMING IN CORAL REEFS—LIME WHENCE DERIVED—SUPPOSED INCREASE OF CALCAREOUS MATTER IN MODERN EPOCHS CONTROVERTED—CONCLUDING REMARKS.

THE powers of the organic creation in modifying the form and structure of the earth's crust are most conspicuously displayed in the labours of the coral animals. We may compare the operation of these zoophytes in the ocean to the effects produced on a smaller scale upon the land by the plants which generate peat. In the case of the Sphagnum, the upper part vegetates while the lower portion is entering into a mineral mass, in which the traces of organisation remain when life has entirely ceased. In corals, in like manner, the more durable materials of the generation that has passed away serve as the foundation on which the living animals continue to rear a similar structure.

The stony part of the lamelliform zoophyte may be likened to an internal skeleton; for it is always more or less surrounded by a soft animal substance capable of expanding itself; yet, when alarmed, it has the power of contracting and drawing itself almost entirely into the cells and hollows of the hard coral. Although oftentimes beautifully coloured in their own element, the soft parts become when taken from

the sea nothing more in appearance than a brown slime spread over the stony nucleus.*

The growth of those corals which form reefs of solid stone is entirely confined to the warmer regions of the globe, rarely extending beyond the tropics more than two or three degrees, except under peculiar circumstances, as in the Bermuda Islands, in lat. 32° N., where the Atlantic is made warmer by the Gulf-stream. The Caribbean seas are very coralliferous. The Pacific Ocean, throughout a space comprehended between the thirtieth parallels of latitude on each side of the equator, is extremely productive of coral; as also are the Arabian and Persian Gulfs. Coral is also abundant in the sea between the coast of Malabar and the island of Madagascar. Flinders describes a reef of coral on the east coast of New Holland as having a length of nearly 1,000 miles, and as being in one part unbroken for a distance of 350 miles. Some groups of coral islands in the Pacific are from 1,100 to 1,200 miles in length, by 300 or 400 in breadth, as the Dangerous Archipelago, for example, and that called Radack by Kotzebue; but the islands within these spaces are always small points, and often very thinly sown.

Fig. 152.

Mœandrina labyrinthica, Lam.
Syn. *Cœloria labyrinthica*.
M. Edw. & J. Haimes.

MM. Duchassaing and Jean Michelotti have written a concise account of the distribution of reef corals in relation to the depth of the sea.† A certain number of zoophytes are littoral and are left uncovered by every low tide—for instance, species of the genera *Zoanthes* and *Palythoa*. In shallow spots where a certain depth of water always covers the corals, the species of *Porites*, *Astræa*, *Madrepora*, *Solenastræa*, and *Phyllangia* flourish. The *Mœandrinæ* are sometimes left uncovered. All

* Ehrenberg, Nat. und Bild. der Coralleninseln, &c., Berlin, 1834.

† Supplément au Mémoire sur les Coralliaires des Antilles. Mem. della Reale Accad. delle Scienze di Torino, série II. tom. xxiii.

these may be termed sub-littoral. At a depth of from 6 to 10 feet the genera Mussa, Colpophyllia, Lithophyllia, Symphyllia, Millepora, &c., are found, and at the depth of from 10 to 20 feet the species of Dichocœnia, Stephanocœnia, and Desmophyllum flourish.

The distribution of particular species, in regard to the depth of water in which they grow, is remarkably uniform. According to Mr. Darwin, as will appear in the sequel, the reef-building corals rarely live at a depth exceeding 120 feet, but M. Duchassaing obtained some species of stony corals at depths of from 600 to 900 feet in the Caribbean Sea. In temperate climates such species as the *Caryophyllia Smythi*, Stokes, are sub-littoral; but Dr. Duncan reminds me, and the fact is of no small geological significance when we are reasoning on extinct forms, that the closely allied species *C. borealis* now lives in deep water off the Shetlands. I learn from Dr. Duncan that the coral fauna of the deep and abyssal sea to a depth of 1,750 fathoms presents species differing in their general anatomy from those which enter into the composition of reefs and atolls. The deep-sea corals do not unite in masses, but are usually simple, solitary, and when aggregated are branched. None of these forms possess the cellular cœnenchyma between the corallites which strengthen the massive reef-builders. All the deep-sea corals of modern and of past times thus differ from reef-builders.*

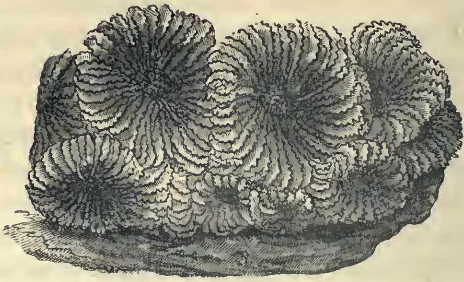
Of the numerous zoophytes which are engaged in the production of coral banks, some of the most common belong to the Lamarckian genera Astræa, Porites, Madrepora, Millepora, Pocillopora, and Mæandrina. (See figs. p. 590.)

Rate of the growth of coral.—Very different opinions have been entertained in regard to the rate at which coral reefs increase. In Captain Beechey's late expedition to the Pacific, no positive information could be obtained of any channel having been filled up within a given period; and it seems established, that several reefs had remained for more than half a century at about the same depth from the surface.

Ehrenberg also questions the fact of channels and harbours having been closed up in the Red Sea by the rapid

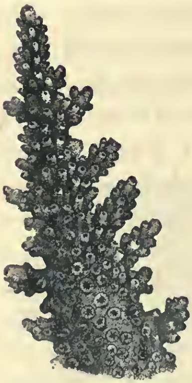
* P. M. Duncan, Coral Faunas of Europe, Quart. Geol. Journ. Soc.

Fig. 153.
Genera of Zoophytes most common in coral reefs.



Astræa dipsacea, Ehrenb. sp. Syn. *Acanthastræa grandis*, Milne Edw. & J. Haimes.

Fig. 154.

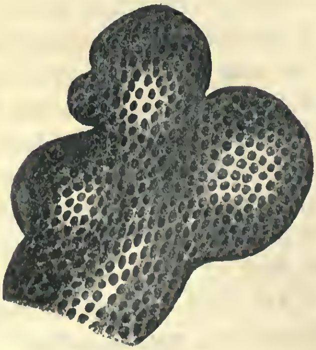


Extremity of branch of *Madrepora muricata*, Lin.

Fig. 155.

Caryophyllia fastigiata, Lam. Syn. *Eusmilia fastigiata*, Milne Edw. & J. Haimes.

Fig. 156.



Porites clavaria, Lam.

Fig. 157.

Oculina hirtella, Lam.

increase of coral limestone. He supposes the notion to have arisen from the circumstance of havens having been occasionally filled up in some places with coral sand, in others with large quantities of ballast of coral rock thrown down from vessels.

The natives of the Bermuda Islands point out certain corals now growing in the sea, which, according to tradition, have been living in the same spots for centuries. It is supposed that some of them may vie in age with the most ancient trees of Europe. Ehrenberg also observed single corals of the genera Mæandrina and Favia, having a globular form, from 6 to 9 feet in diameter, 'which must (he says) be of immense antiquity, probably several thousand years old, so that Pharaoh may have looked upon these same individuals in the Red Sea.' * They certainly imply, as he remarks, that the reef on which they grow has increased at a very slow rate. After collecting more than 100 species, he found none of them covered with parasitic zoophytes, nor any instance of a living coral growing on another living coral. To this repulsive power which they exert whilst living, against all others of their own class, we owe the beautiful symmetry of some large Mæandrinæ, and other species which adorn our museums. Yet Balani and Serpulæ can attach themselves to the dermal tissues of living corals, and holes are excavated in them by boring mollusks.

At the island called Taaopoto, in the South Pacific, the anchor of a ship, wrecked about 50 years before, was observed in seven fathoms' water, still preserving its original form, but entirely incrusted by coral.† This fact would seem to imply a slow rate of augmentation; but to form a correct estimate of the average rate must be very difficult, since it must vary not only according to the species of coral, but according to the circumstances under which each species may be placed; such, for example, as the depth from the surface, the quantity of light, the temperature of the water, its freedom from sand or mud, or the absence or presence of breakers, which is favourable to the growth of some kinds and fatal to that

* See Ehrenberg's work above cited, p. 751.

† Stuchbury, West of England Journal, No. i. p. 49.

of others. It should also be observed that the apparently stationary condition of some coral reefs, which according to Beechey have remained for centuries at the same depth under water, may be due to subsidence, the upward growth of the coral having been just sufficient to keep pace with the sinking of the solid foundation on which the zoophytes have built. We shall afterwards see how far this hypothesis is borne out by other evidence in the regions of annular reefs or atolls.

In one of the Maldive Islands a coral reef, which, within a few years, existed as an islet bearing cocoa-nut trees, was found by Lieutenant Prentice, '*entirely covered with live coral and madrepore.*' The natives stated that the islet had been washed away by a change in the currents, and it is clear that a coating of growing coral had been formed in a short time.* Experiments, also, of Dr. Allan, on the east coast of Madagascar, prove the possibility of coral growing to a thickness of three feet in about half a year;† so that the rate of increase may, under favourable circumstances, be very far from slow.

It must not be supposed that the calcareous masses termed coral reefs are exclusively the work of zoophytes: a great variety of shells, and, among them, some of the largest and heaviest of known species, contribute to augment the mass. In the South Pacific, great beds of Serpulæ, oysters, mussels, *Pinnæ marinæ*, *Chamæ* (or *Tridacnæ*), and other shells cover in profusion almost every reef; and on the beach of coral islands are seen the shells of echini and broken fragments of crustaceous animals. Large shoals of fish are also discernible through the clear blue water, and their teeth and hard palates cannot fail to be often preserved, although their soft cartilaginous bones may decay.

It was the opinion of the German naturalist Forster, in 1780, after his voyage round the world with Captain Cook, that coral animals had the power of building up steep and almost perpendicular walls from great depths in the sea, a notion afterwards adopted by Captain Flinders and others;

* Darwin's Coral Reefs, p. 77. † Ibid. p. 78.

but it is now very generally believed that most of these zoophytes cannot live in water of great depths.

Mr. Darwin has come to the conclusion, that those species which are most effective in the construction of reefs, rarely flourish at a greater depth than 20 fathoms, or 120 feet. In some lagoons, however, where the water is but little agitated, there are, according to Kotzebue, beds of living coral in 25 fathoms' water, or 150 feet; but these may perhaps have begun to live in shallower water, and may have been carried downwards by the subsidence of the reef. There are also various species of zoophytes, and among them some which are provided with calcareous as well as horny stems, which live in much deeper water, even in some cases to a depth of 180 fathoms; but these do not appear to give origin to stony reefs.

There is every variety of form in coral reefs, but the most remarkable and numerous in the Pacific consist of circular

Fig. 158.

View of Whitsunday Island. (Capt. Beechey.)*

or oval strips of dry land, enclosing a shallow lake or lagoon of still water, in which zoophytes and mollusca abound. The annular reefs just raise themselves above the level of the sea, and are surrounded by a deep and often unfathomable ocean.

In the annexed cut (fig. 158), one of these circular islands

* Voyage to the Pacific, &c. in 1825–28.

is represented, just rising above the waves, covered with the cocoa-nut and other trees, and enclosing a lagoon of tranquil water, whose vivid green colour contrasts strikingly with the deep blue of the surrounding ocean.

The accompanying section will enable the reader to comprehend the usual form of such islands. (Fig. 159.)

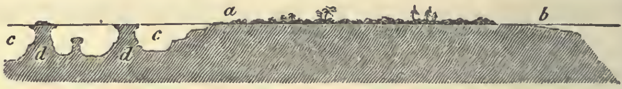
Fig. 159.

Section of a Coral Island.

a, a. Habitablo part of the island, consisting of a strip of coral, enclosing the lagoon.
b, b. The lagoon.

The subjoined cut (fig. 160) exhibits a small part of the section of a coral island on a larger scale.

Fig. 160.



Section of part of a Coral Island.

a, b. Habitable part of the island.
b, b. Slope of the side of the island, plunging at an angle of forty-five to the depth of fifteen hundred feet.
c, c. Part of the lagoon.
d, d. Knolls of coral in the lagoon, with overhanging masses of coral resembling the capitals of columns.

Of thirty-two of these coral islands visited by Beechey in his voyage to the Pacific, twenty-nine had lagoons in their centres. The largest was 30 miles in diameter, and the smallest less than a mile. All were increasing their dimensions by the active operations of the lithophytes, which appeared to be gradually extending and bringing the immersed parts of their structure to the surface. The scene presented by these annular reefs is equally striking for its singularity and beauty. A strip of land a few hundred yards wide is covered by lofty cocoa-nut trees, above which is the blue vault of heaven. This band of verdure is bounded by a beach of glittering white sand, the outer margin of which is encircled with a ring of snow-white breakers, beyond which are the dark heaving waters of the ocean. The inner beach encloses the still clear water of the lagoon, resting in its greater

part on white sand, and when illuminated by a vertical sun, of a most vivid green.* Certain species of zoophytes abound most in the lagoon, others on the exterior margin, where there is a great surf. 'The ocean,' says Mr. Darwin, 'throwing its breakers on these outer shores, appears an invincible enemy, yet we see it resisted and even conquered by means which at first seem most weak and inefficient. No periods of repose are granted, and the long swell caused by the steady action of the trade wind never ceases. The breakers exceed in violence those of our temperate regions, and it is impossible to behold them without feeling a conviction that rocks of granite or quartz would ultimately yield and be demolished by such irresistible forces. Yet these low insignificant coral islets stand and are victorious, for here another power, as antagonist to the former, takes part in the contest. The organic forces separate the atoms of carbonate of lime one by one from the foaming breakers, and unite them into a symmetrical structure; myriads of architects are at work night and day, month after month, and we see their soft and gelatinous bodies through the agency of the vital laws conquering the great mechanical power of the waves of an ocean, which neither the art of man, nor the inanimate works of nature, could successfully resist.'†

As the coral animals require to be continually immersed in salt water, they cannot raise themselves by their own efforts above the level of the lowest tides. The manner in which the reefs are converted into islands above the level of the sea is thus described by Chamisso, a naturalist who accompanied Kotzebue in his voyages:—'When the reef,' says he, 'is of such a height that it remains almost dry at low water, the corals leave off building. Above this line a continuous mass of solid stone is seen composed of the shells of mollusks and echini, with their broken-off prickles and fragments of coral, united by calcareous sand, produced by the pulverisation of shells. The heat of the sun often penetrates the mass of stone when it is dry, so that it splits in many places, and the force of the waves is thereby enabled to separate and lift

* Darwin's Journal, &c., p. 540, and new edit., of 1845, p. 453.

† Ibid. pp. 547, 548, and 2nd edit., of 1845, p. 460.

blocks of coral, frequently six feet long and three or four in thickness, and throw them upon the reef, by which means the ridge becomes at length so high that it is covered only during some seasons of the year by the spring tides. After this the calcareous sand lies undisturbed, and offers to the seeds of trees and plants cast upon it by the waves a soil upon which they rapidly grow, to overshadow its dazzling white surface. Entire trunks of trees, which are carried by currents from other countries and islands, find here, at length, a resting-place after their long wanderings: with these come some small animals, such as insects and lizards, as the first inhabitants. Even before the trees form a wood, the sea-birds nestle here; stray land-birds take refuge in the bushes; and, at a much later period, when the work has been long since completed, man appears and builds his hut on the fruitful soil.' *

In the above description the solid stone is stated to consist of shell and coral, united by sand; but masses of very compact limestone are also found even in the uppermost and newest parts of the reef, such as could only have been produced by chemical precipitation. Professor Agassiz also informs me that his observations on the Florida reefs (which confirm Darwin's theory of atolls, to be mentioned in the sequel) have convinced him that large blocks are loosened, not by shrinkage in the sun's heat, as Chamisso imagined, but by innumerable perforations of lithodomi and other boring testacea. The carbonate of lime may have been principally derived from the decomposition of corals and testacea; for when the animal matter undergoes putrefaction, the calcareous residuum must be set free under circumstances very favourable to precipitation, especially when there are other calcareous substances, such as shells and corals, on which it may be deposited. Thus organic bodies may be enclosed in a solid cement, and become portions of rocky masses.†

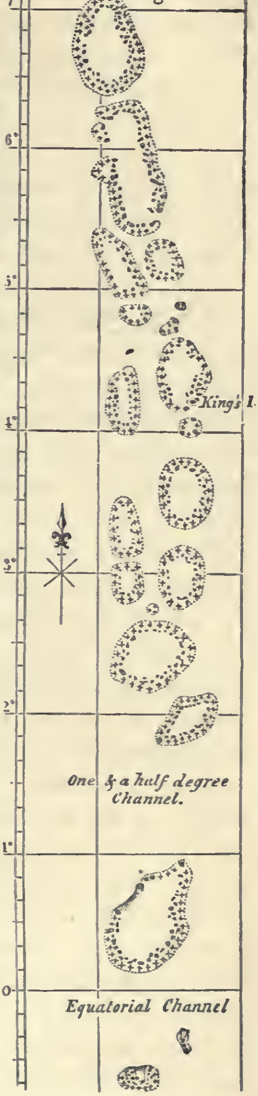
The width of the circular strip of dead coral forming the islands explored by Captain Beechey, exceeded in no instance half a mile from the usual wash of the sea to the edge of the

* Kotzebue's Voy., 1815–18, vol. iii. pp. 331–333.

† Stuchbury, West of Eng Journ., No. i. p. 50, and P. M. Duncan, Quart. Journ. Geol. Soc., Nov. 1864, p. 360.

lagoon, and, in general, was only about three or four hundred yards.* The depth of the lagoons is various; in some, entered by Captain Beechey, it was from 20 to 38 fathoms. The two other peculiarities which are most characteristic of the annular reef or atoll are first, that the strip of dead coral is invariably highest on the windward side, and secondly, that there is very generally an opening at some point in the reef affording a narrow passage, often of considerable depth, from the sea into the lagoon. The origin of this passage and its connection with the subsidence of the coral areas will be considered (p. 608).

Fig. 161.



Maldive and Laccadive Isles.—The reefs and islets called the Maldives (see fig. 161), situated in the Indian Ocean, to the south-west of Malabar, form a chain 470 geographical miles in length, running due north and south, with an average breadth of about 50 miles. It is composed throughout of a series of circular assemblages of islets, all formed of coral, the larger groups being from 40 to 90 miles in their longest diameter. Captain Horsburgh, whose chart of these islands is subjoined, states, that outside of each circle or *atoll*, as it is termed, there are coral reefs sometimes extending to the distance of two or three miles, beyond which there are no soundings at immense depths. But in the centre of each atoll there is a lagoon from 15 to 49 fathoms deep. In the channels between the atolls no soundings can usually be obtained at the depth of 150 or even 250 fathoms, but during Captain Moresby's survey, sound-

* Captain Beechey, part i. p. 188.

ings were struck at 150 and 200 fathoms, the only instances as yet known of the bottom having been reached, either in the Indian or Pacific Oceans, in a space intervening between two separate and well-characterised atolls.

The singularity in the form of the atolls of this archipelago consists in their being made up, not of one continuous circular reef, but of a ring of small coral islets sometimes more than a hundred in number, each of which is a ring-shaped strip of coral surrounding a lagoon of salt water. To account for the origin of these, Mr. Darwin supposes the larger annular reef to have been broken up into a number of fragments, each of which acquired its peculiar configuration under the influence of causes similar to those to which the structure of the parent atoll has been due. Many of the minor rings are no less than three, and even five miles in diameter, and some are situated in the midst of the principal lagoon; but this happens only in cases where the sea can enter freely through breaches in the outer or marginal cave.

The rocks of the Maldives are composed of limestone formed of broken shells and corals, such as may be obtained in a loose state from the beach, and which is seen when exposed for a few days to the air to become hardened. The limestone is sometimes observed to be an aggregate of broken shells, corals, pieces of wood, and shells of the cocoa-nut.*

The Laccadive Islands run in the same line with the Maldives, on the north, as do the islands of the Chagos Archipelago, on the south; so that these may be continuations of the same chain of submerged mountains, crested in a similar manner by coral limestones.

Origin of the circular form—not volcanic.—The circular and oval shape of so many reefs, each having a lagoon in the centre, and being surrounded on all sides by a deep ocean, naturally suggested the idea that they were nothing more than the crests of submarine volcanic craters overgrown by coral; and this theory I myself advocated in the earlier

* Captain Moresby on the Maldives, Journ. Roy. Geograph. Soc., vol. v. part ii. p. 400.

editions of this work. Although I am now about to show that it must be abandoned, it may still be instructive to point out the grounds on which it was formerly embraced. In the first place, it had been remarked that there were many active volcanos in the coral region of the Pacific, and that in some places, as in Gambier's group, rocks composed of porous lava rise up in a lagoon bordered by a circular reef, just as the two cones of eruption called the Kaimenis have made their appearance in the times of history within the circular gulf of Santorin.* It was also observed that as in S. Shetland, Barren Island, and others of volcanic origin, there is one narrow breach in the walls of the outer cone by which ships may enter a circular gulf, so in like manner there is often a single deep passage leading into the lagoon of a coral island, the lagoon itself seeming to represent the hollow or gulf just as the ring of dry coral recalls to our minds the rim of a volcanic crater. More lately, indeed, Mr. Darwin has shown that the numerous volcanic craters of the Galapagos Archipelago in the Pacific have all of them their southern sides the lowest, or in many cases quite broken down, so that if they were submerged and incrusted with coral, they would resemble true atolls in shape.†

Another argument which I adduced when formerly defending this doctrine was derived from Ehrenberg's statement, that some banks of coral in the Red Sea were square, while many others were ribbon-like strips, with flat tops, and without lagoons. Since, therefore, all the genera and many of the species of zoophytes in the Red Sea agreed with those which elsewhere construct lagoon islands, it followed that the stone-making zoophytes are not guided by their own instinct in the formation of annular reefs, but that this peculiar shape and the position of such reefs in the midst of a deep ocean must depend on the outline of the submarine bottom, which resembles nothing else in nature but the crater of a lofty submerged volcanic cone. The enormous size, it is true, of some atolls made it necessary for me to ascribe to the craters of many submarine volcanos a magnitude which was startling, and which had often been appealed to as a serious objection

* See above, p. 69.

† Darwin, Volcanic Islands, p. 112.

to the volcanic theory. That so many of them were of the same height, or just level with the water, did not present a difficulty so long as we remained ignorant of the fact that the reef-building species do not grow at greater depths than 25 fathoms.

May be explained by subsidence.—Mr. Darwin, after examining a variety of coral formations in different parts of the globe, was induced to reject the opinion that their shape represented the form of the original bottom. Instead of admitting that the ring of dead coral rested on a circular or oval ridge of rock, or that the lagoon corresponded to a pre-existing cavity, he advanced a new opinion, which must, at first sight, seem paradoxical in the extreme: namely, that the lagoon is precisely in the place once occupied by the highest part of a mountainous island, or, in other cases, by the top of a shoal.

The following is a brief sketch of the facts and arguments in favour of this new view:—Besides those rings of dry coral which enclose lagoons, there are others having a similar form and structure which encircle lofty islands. Of the latter kind is Vanikoro (see Map, fig. 65, p. 587, Vol. I.), celebrated on account of the shipwreck of La Peyrouse, where the coral reef runs at the distance of two or three miles from the shore, the channel between it and the land having a general depth of between 200 and 300 feet. This channel, therefore, is analogous to a lagoon, but with an island standing in the middle. In like manner in Tahiti we see a mountainous land, with everywhere round its margin a lake or zone of smooth salt water, separated from the ocean by an encircling reef of coral, on which a line of breakers is always foaming. So also New Caledonia, a long narrow island east of New Holland, composed partly of granite and partly of triassic sandstone, is surrounded by a reef 400 miles long. This reef encompasses not only the island itself, but a ridge of rocks which is prolonged in the same direction beneath the sea. No one, therefore, will contend for a moment that in this case the corals are based upon the rim of a volcanic crater, in the middle of which stands a mountain or island of granite or sandstone.

The great barrier reef, already mentioned as running parallel to the north-east coast of Australia for nearly 1,000 miles, is another most remarkable example of a long strip of coral running parallel to a coast. Its distance from the mainland varies from 20 to 70 miles, and the depth of the great arm of the sea thus enclosed is usually between 10 and 20 fathoms, but towards one end from 40 to 60. This great reef would extend much farther, according to Mr. Jukes, if the growth of coral were not prevented off the shores of New Guinea by a muddy bottom, caused by rivers charged with sediment which flow from the southern coast of that great island.*

Two classes of reefs, therefore, have now been considered; first, the atoll, and, secondly, the encircling and barrier reef, both agreeing perfectly in structure, and the sole difference lying in the absence in the case of the atoll of all land, and in the others the presence of land bounded either by an encircling or a barrier reef. But there is still a third class of reefs, called by Mr. Darwin 'fringing reefs,' which approach much nearer the land than those of the encircling and barrier class, and which indeed so nearly touch the coast as to leave nothing in the intervening space resembling a lagoon. 'That these reefs are not attached quite close to the shore appears to be the result of two causes; first, that the water immediately adjoining the beach is rendered turbid by the surf, and therefore injurious to all zoophytes; and, secondly, that the larger and efficient kinds only flourish on the outer edges amidst the breakers of the open sea.'†

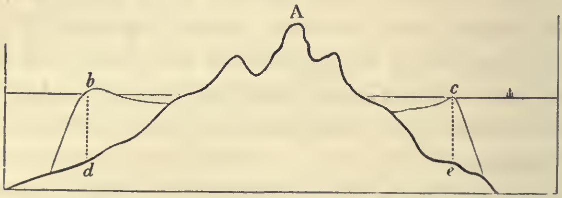
It will at once be conceded that there is so much analogy between the form and position of the strip of coral in the atoll, and in the encircling and barrier reef, that no explanation can be satisfactory which does not include the whole. If we turn, in the first place, to the encircling and barrier reefs, and endeavour to explain how the zoophytes could have found a bottom on which to begin to build, we are met at once with a great difficulty. It is a general fact, long since

* Quart. Journ. Geol. Soc. 4, xciii.

† Darwin's Journ., p. 557, 2nd edit. chap. 20, and Coral Islands, chapters 1, 2, 3.

remarked by Dampier, that high land and deep seas go together. In other words, steep mountains coming down abruptly to the sea-shore are generally continued with the same slope beneath the water. But where the reef, as at *b c* (fig. 162), is distant several miles from a steep coast, a line

Fig. 162.



Supposed section of an island with an encircling reef of coral.

A. The island.

b, c. Highest points of the encircling reef between which and the coast is seen a space occupied by still water.

drawn perpendicularly downwards from its outer edges *b c*, to the fundamental rock *d e*, must descend to a depth exceeding by several thousand feet the limits at which the efficient stone-building corals can exist, for we have seen that they cease to grow in water which is more than 120 feet deep. That the original rock immediately beneath the points *b c* is actually as far from the surface *d e*, is not merely inferred from Dampier's rule, but confirmed by the fact, that, immediately outside the reef, soundings are either not met with at all, or only at enormous depths. In short, the ocean is as deep as might have been anticipated in the neighbourhood of a bold coast; and it is obviously the presence of the coral alone which has given rise to the anomalous existence of shallow water on the reef and between it and the land.

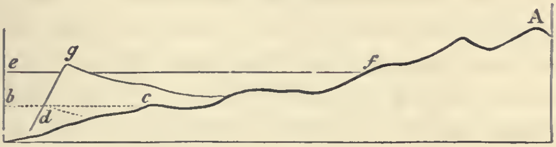
After studying in minute detail all the phenomena above described, Mr. Darwin has offered in explanation a theory now very generally adopted. The coral-forming polypi, he states, begin to build in water of a moderate depth, and, while they are yet at work, the bottom of the sea subsides gradually, so that the foundation of their edifice is carried downwards at the same time that they are raising the superstructure. If, therefore, the rate of subsidence be not too rapid, the growing coral will continue to build up to the surface;

the mass always gaining in height above its original base, but remaining in other respects in the same position. Not so with the land: each inch lost is irreclaimably gone; as it sinks the water gains foot by foot on the shore, till in many cases the highest peak of the original island disappears. What was before land is then occupied by the lagoon, the position of the encircling coral remaining unaltered, with the exception of a slight contraction of its dimensions.

In this manner are encircling reefs and atolls produced; and in confirmation of his views Mr. Darwin has pointed out examples which illustrate every intermediate state, from that of lofty islands such as Otaheite, encircled by coral, to that of Gambier's group, where a few peaks only of land rise out of a lagoon, and, lastly, to the perfect atoll, having a lagoon several hundred feet deep, surrounded by a reef rising deeply from an unfathomed ocean.

If we embrace these views, it is clear, that in regions of growing coral a similar subsidence must give rise to barrier

Fig. 163.



reefs along the shores of a continent. Thus suppose A (fig. 163) to represent the north-east portion of Australia, and *b c* the ancient level of the sea, when the coral reef *d* was formed. If the land sink so that it is submerged more and more, the sea must at length stand at the level *e f*, the reef in the meantime having been enlarged and raised to the point *g*. The distance between the shore *f*, and the barrier reef *g*, is now much greater than originally between the shore *c* and the reef *d*, and the longer the subsidence continues the farther will the coast of the mainland recede.

When the first edition of this work appeared in 1831, several years before Mr. Darwin had investigated the facts on which this theory is founded, I had come to the opinion that the land was subsiding at the bottom of those parts of

the Pacific where atolls are numerous, although I failed to perceive that such a subsidence, if conceded, would equally solve the enigma as to the form both of annular and barrier reefs.

I shall cite the passage referred to, as published by me in 1831:—'It is a remarkable circumstance that there should be so vast an area in Eastern Oceanica, studded with minute islands, without one single spot where there is a wider extent of land than belongs to such islands as Otaheite, Owhyhee, and a few others, which either have been or are still the seats of active volcanos. If an equilibrium only were maintained between the upheaving and depressing force of earthquakes, large islands would very soon be formed in the Pacific; for, in that case, the growth of limestone, the flowing of lava, and the ejection of volcanic ashes, would combine with the upheaving force to form new land.

'Suppose a shoal, 600 miles in length, to sink 15 feet, and then to remain unmoved for a thousand years; during that interval the growing coral may again approach the surface. Then let the mass be re-elevated 15 feet, so that the original reef is restored to its former position: in this case, the new coral formed since the first subsidence will constitute an island 600 miles long. An analogous result would have occurred if a lava-current 15 feet thick had overflowed the submerged reef. The absence, therefore, of more extensive tracts of land in the Pacific seems to show that the amount of subsidence by earthquakes exceeds, in that quarter of the globe, at present, the elevation due to the same cause.' *

Another proof also of subsidence derived from the structure of atolls, was pointed out by me in the following passage in all former editions. 'The low coral islands of the Pacific,' says Captain Beechey, 'follow one general rule in having their windward side higher and more perfect than the other. At Gambier and Matilda Islands this inequality is very conspicuous, the weather side of both being wooded, and of the former inhabited, while the other sides are from

* See Principles of Geology, 1st edit., vol. ii. p. 296.

20 to 30 feet under water; where, however, they may be perceived to be equally *narrow* and well defined. It is on the leeward side also that the entrances into the lagoons occur; and although they may sometimes be situated on a side that runs in the direction of the wind, as at Bow Island, yet there are none to windward.' These observations of Captain Beechey accord with those which Captain Horsburgh and other hydrographers have made in regard to the coral islands of other seas. From this fortunate circumstance ships can enter and sail out with ease; whereas if the narrow inlets were to windward, vessels which once entered might not succeed for months in making their way out again. The well-known security of many of these harbours depends entirely on this fortunate peculiarity in their structure.

'In what manner is this singular conformation to be accounted for? The action of the waves is seen to be the cause of the superior elevation of some reefs on their windward sides, where sand and large masses of coral rock are thrown up by the breakers; but there is a variety of cases where this cause alone is inadequate to solve the problem; for reefs submerged at considerable depths, where the movements of the sea cannot exert much power, have, nevertheless, the same conformation, the leeward being much lower than the windward side.*

'I am informed by Captain King, that, on examining the reefs called Rowley Shoals, which lie off the north-west coast of Australia, where the east and west monsoons prevail alternately, he found the open side of one crescent-shaped reef, the Impérieuse, turned to the east, and of another, the Mermaid, turned to the west; while a third oval reef, of the same group, was entirely submerged. This want of conformity is exactly what we should expect, where the winds vary periodically.

'It seems impossible to refer the phenomenon now under consideration to any original uniformity in the configuration of submarine volcanos, on the summits of which we may

* Voyage to the Pacific, &c., p. 189.

suppose the coral reefs to grow; for although it is very common for craters to be broken down on one side only, we cannot imagine any cause that should breach them all in the same direction. But the difficulty will, perhaps, be removed, if we call in another part of the volcanic agency—subsidence by earthquakes. Suppose the windward barrier to have been raised by the mechanical action of the waves to the height of 2 or 3 yards above the wall on the leeward side, and then the whole island to sink down a few fathoms, the appearances described would then be presented by the submerged reef. A repetition of such operations, by the alternate elevation and depression of the same mass (an hypothesis strictly conformable to analogy), might produce still greater inequality in the two sides, especially as the violent efflux of the tide has probably a strong tendency to check the accumulation of the more tender corals on the leeward reef; while the action of the breakers contributes to raise the windward barrier.'*

Previously to my adverting to the signs above enumerated of a downward movement in the bed of the ocean, Dr.

Fig. 164.

Elizabeth or Henderson's Island.

Macculloch, Captain Beechey, and many other writers had shown that masses of recent coral had been laid dry at various heights above the sea-level, in the Red Sea, the islands of the Pacific, and in the East and West Indies. After describing thirty-two coral islands in the Pacific, Captain Beechey mentioned that they were all formed of living coral except one, which, although of coral formation, was raised about 70 or 80 feet above the level of the sea, and was encompassed by a reef of living coral. It is called Elizabeth or Henderson's Island, and is 5 miles in length by 1 in breadth. It has a flat surface, and, on all sides, except the north, is bounded by perpendicular cliffs above 50 feet high, composed entirely of dead coral, more or less

* See Principles of Geol., 1st edit., 1832, vol. ii. p. 293.

porous, honeycombed at the surface, and hardening into a compact calcareous mass, which possesses the fracture of secondary limestone, and has a species of millepore interspersed through it. These cliffs are considerably undermined by the action of the waves, and some of them appear on the eve of precipitating their superincumbent weight into the sea. Those which are less injured in this way present no alternate ridges or indication of the different levels which the sea might have occupied at different periods; but a smooth surface, as if the island, which has probably been raised by volcanic agency, had been forced up by one great subterraneous convulsion.* At the distance of a few hundred yards from this island, no bottom could be gained with 200 fathoms of line.

It will be seen, from the annexed sketch, communicated to me by Lieutenant Smith, of the Blossom, that the trees came down to the beach towards the centre of the island, where there is a break in the cliffs resembling at first sight the openings which usually lead into lagoons; but the trees stand on a steep slope, and no hollow of an ancient lagoon was perceived. Beechey also remarks, that the surface of Henderson's Island is flat, and that in Queen Charlotte's Island, one of the same group, but under water, there was no lagoon, the coral having grown up everywhere to one level. The probable cause of this obliteration of the central basin or lagoon will be considered in the sequel.

That the bed of the Pacific and Indian Oceans, where atolls are frequent, must have been sinking for ages, might be inferred, says Mr. Darwin, from simply reflecting on two facts; first, that the efficient coral-building zoophytes do not flourish in the ocean at a greater depth than 120 feet; and, secondly, that there are spaces occupying areas of many hundred thousand square miles, where all the islands consist of coral, and yet none of which rise to a greater height than may be accounted for by the action of the winds and waves on broken and triturated coral. Were we to take for granted that the floor of the ocean had remained stationary from the time when the coral began to grow, we should be compelled

* Beechey's Voyage to the Pacific, &c., p. 46.

to assume that an incredible number of submarine mountains of vast height (for the ocean is always deep, and often unfathomable between the different atolls) had all come to within 120 feet of the surface, and yet no one mountain had risen above water. But no sooner do we admit the theory of subsidence than this great difficulty vanishes. However varied may have been the altitude of different islands, or the separate peaks of particular mountain-chains, all may have been reduced to one uniform level by the gradual submergence of the loftiest points and the additions made to the calcareous cappings of the less elevated summits as they subsided to great depths.

Openings into the lagoons.—In the general description of atolls and encircling reefs, it was mentioned that there is almost always a deep narrow passage opening into the lagoon, or into the still water between the reef and the shore, which is kept open by the efflux of the sea as the tide goes down.

The origin of this channel must, according to the theory of subsidence before explained, be traced back to causes which were in action during the existence of the encircling reef, and when an island or mountain top rose within it, for such a reef precedes the atoll in the order of formation. Now in those islands in the Pacific, which are large enough to feed small rivers, there is generally an opening or channel in the surrounding coral reef at the point where the stream of fresh water enters the sea. The depth of these channels rarely exceeds 25 feet; and they may be attributed, says Captain Beechey, to the aversion of the lithophytes to fresh water, and to the probable absence of the mineral matter of which they construct their habitations.*

Mr. Darwin, however, has shown, that mud at the bottom of river-courses is far more influential than the freshness of the water in preventing the growth of the polypi, for the walls which enclose the openings are perpendicular, and do not slant off gradually, as would be the case, if the nature of the element presented the only obstacle to the increase of the coral-building animals.

* Voyage to the Pacific, &c., p. 194.

When a breach has thus been made in the reef it will be prevented from closing up by the efflux of the sea at low tides; for it is sufficient that a reef should rise a few feet above low-water mark to cause the waters to collect in the lagoon at high tide, and when the sea falls, to rush out at one or more points where the reef happens to be lowest or weakest. This event is strictly analogous to that witnessed in our estuaries, where a body of salt water accumulated during the flow issues with great velocity at the ebb of the tide, and scours out or keeps open a deep passage through the bar which is almost always formed at the mouth of a river. At first there are probably many openings, but the growth of the coral tends to obstruct all those which do not serve as the principal channels of discharge; so that their number is gradually reduced to a few, and often finally to one. The fact observed universally, that the principal opening fronts a considerable valley in the encircled island, between the shores of which and the outer reef there is often deep water, scarcely leaves any doubt as to the real origin of the channel in all those countless atolls where the nucleus of land has vanished.

Size of atolls and barrier reefs.—In regard to the dimensions of atolls, it was stated that some of the smallest observed by Beechey in the Pacific were only a mile in diameter. If their external slope under water equals upon an average an angle of 45°, then such an atoll at the depth of half a mile, or 2,640 feet, would have a diameter of two miles. Hence it would appear that there must be a tendency in every atoll to grow smaller, except in those cases where oscillations of level enlarge the base on which the coral grows by throwing down a talus of detrital matter all round the original cone of limestone.

Bow Island is described by Captain Beechey as 70 miles in circumference and 30 in its greatest diameter, but we have seen that some of the Maldives are much larger.

As the shore of an island or continent which is subsiding will recede from a coral reef at a slow or rapid rate according as the surface of the land has a steep or gentle slope, we cannot measure the thickness of the coral by its distance

from the coast; yet, as a general rule, those reefs which are farthest from the land imply the greatest amount of subsidence. We learn from Flinders, that the barrier reef of north-eastern Australia is in some places 70 miles from the mainland, and it would seem that the calcareous formation is there in progress 1,000 miles long from north to south, with a breadth varying from 20 to 70 miles. It may not, indeed, be continuous over this vast area, for doubtless innumerable islands have been submerged one after another between the reef and mainland, like some which still remain, as, for example, Murray's Islands, lat. 9° 54′ S. We are told that some parts of the gulf enclosed within the barrier are 400 feet deep, so that the efficient rock-building corals cannot be growing there, and in other parts of it islands appear encircled by reefs.

It will follow as one of the consequences of the theory already explained that, provided the bottom of the sea does not sink too fast to allow the zoophytes to build upwards at the same pace, the thickness of coral will be great in proportion to the rapidity of subsidence, so that if one area sinks 2 feet while another sinks 1, the mass of coral in the first area will be double that in the second. But the downward movement must in general have been very slow and uniform, or, where intermittent, must have consisted of a great number of depressions, each of slight amount, otherwise the bottom of the sea would have been carried down faster than the corals could build upwards, and the island or continent would be permanently submerged, having reached a depth of 120 or 150 feet, at which the effective reef-constructing zoophytes cease to live. If, then, the subsidence required to account for all the existing atolls must have amounted to 3,000 or 4,000 feet, or even sometimes more, we are brought to the conclusion that there has been a *slow* and *gradual* sinking to this enormous extent. Such an inference is perfectly in harmony with views which the grand scale of denudation, everywhere observable in the older rocks, has led geologists to adopt in reference to upward movements. They must also have been gradual and continuous throughout indefinite ages to allow the waves and currents of the ocean to operate with adequate power.

The map constructed by Mr. Darwin to display at one view the geographical position of all the coral reefs throughout the globe is of the highest geological interest, leading to splendid generalisations, when we have once embraced the theory that all atolls and barrier reefs indicate recent subsidence, while the presence of fringing reefs proves the land to be stationary or rising. These two classes of coral formations are depicted by different colours; and one of the striking facts brought to light by the same classification of coral formations is the absence of active volcanos in areas of subsidence, and their frequent presence in the areas of elevation. The only supposed exception to this remarkable coincidence at the time when Mr. Darwin wrote, in 1842, was the volcano said to exist in Torres Strait, at the northern point of Australia, placed on the borders of an area of subsidence; but it has been since ascertained that this volcano has no existence.

We see, therefore, an evident connection, first, between the bursting forth every now and then of volcanic matter through rents and fissures, and the expansion or forcing outwards of the earth's crust, and, secondly, between a dormant and less energetic development of subterranean heat, and an amount of subsidence sufficiently great to cause mountains to disappear under the broad face of the ocean, leaving only small and scattered lagoon islands, or groups of atolls, to indicate the spots where those mountains once stood.

On a review of the differently-coloured reefs on the map alluded to it will be seen that there are large spaces in which upheaval, and others in which depression prevails, and these are placed alternately, while there are a few smaller areas where movements of oscillation occur. Thus if we commence with the western shores of South America, between the summit of the Andes and the Pacific (a region of earthquakes and active volcanos), we find signs of recent elevation, not attested by coral formations, which are wanting there, but by upraised banks of marine shells. Then proceeding westward, we traverse a deep ocean without islands, until we come to a band of *atolls* and encircled islands, including the Dangerous and Society archipelagos,

and constituting an area of subsidence more than 4,000 miles long and 600 broad. Still farther, in the same direction, we reach the chain of islands to which the New Hebrides, Solomon, and New Ireland belong, where fringing reefs and masses of elevated coral indicate another area of upheaval. Again, to the westward of the New Hebrides we meet with the encircling reef of New Caledonia and the great Australian barrier, implying a second area of subsidence.

The only objection deserving attention which has hitherto been advanced against the theory of atolls, as before explained (p. 600), is that proposed by Mr. Maclaren.* 'On the outside,' he observes, 'of coral reefs very highly inclined, no bottom is sometimes found with a line of 2,000 or 3,000 feet, and this is by no means a rare case. It follows that the reef ought to have this thickness; and Mr. Darwin's diagrams show that he understood it so. Now, if such masses of coral exist under the sea, they ought somewhere to be found on *terra firma;* for there is evidence that all the lands yet visited by geologists have been at one time submerged. But neither in the great volcanic chain, extending from Sumatra to Japan, nor in the West Indies, nor in any other region yet explored, has a bed or formation of coral even 500 feet thick been discovered, so far as we know.'

When considering the objection, it is evident that the first question we have to deal with is, whether geologists have not already discovered calcareous masses of the required thickness and structure, or precisely such as the upheaval of atolls might be expected to expose to view? We are called upon, in short, to make up our minds both as to the internal composition of the rocks that must result from the growth of corals, whether in lagoon islands or barrier reefs, and the external shape which the reefs would retain when upraised gradually to a vast height,—a task by no means so easy as some may imagine. If the reader has pictured to himself large masses of entire corals, piled one upon the other, for a thickness of several thousand feet, he unquestionably mistakes altogether the nature of the accumulations now in progress.

* Scotsman, Nov. 1842, and Jameson's Edin. Journ. of Science, 1843.

In the first place, the strata at present forming very extensively over the bottom of the ocean, within such barrier reefs as those of Australia and New Caledonia, are known to consist chiefly of horizontal layers of calcareous sediment, while here and there an intermixture must occur of the detritus of granitic and other rocks brought down by rivers from the adjoining lands, or washed from sea-cliffs by the waves and currents. Secondly, in regard to atolls, the stone-making polypifers grow most luxuriantly on the outer edge of the island, to a thickness of a few feet only. Beyond this margin broken pieces of coral and calcareous sand are strewed by the breakers over a steep seaward slope, and as the subsidence continues, the next coating of live coral does not grow vertically over the first layer, but on a narrow annular space within it, the reef, as was before stated (p. 603), constantly contracting its dimensions as it sinks. Thirdly, within the lagoon the accumulation of calcareous matter is chiefly sedimentary, a kind of chalky mud derived from the decay of the softer corallines, with a mixture of calcareous sand swept by the winds and waves from the surrounding circular reef. Here and there, but only in partial clumps, are found living corals, which grow in the middle of the lagoon, and mixed with these and with fine mud and sand, a great variety of shells, and fragments of testacea and echinoderms.

We owe to Lieutenant Nelson the discovery that in the Bermudas the calcareous mud resulting from the decomposition of the corals and nullipores resembles closely, but not microscopically, the ordinary white chalk of Europe,* and this mud is carried to great distances by currents, and spread far and wide over the floor of the ocean. We also have opportunities of seeing in upraised atolls, such as Elizabeth Island, Tonga, and Hapai, which rise above the level of the sea to heights varying from 10 to 80 feet, that the rocks of which they consist do not differ in structure or in the state of preservation of their included zoophytes and shells from some of the oldest limestones known to the geologist. Captain Beechey remarks that the dead coral in Elizabeth's

* Trans. Geol. Soc. London, 2d series, vol. v.

Island is 'more or less porous and honeycombed at the surface, and hardening into a compact rock which has the fracture of *secondary limestone*.' *

The island of Pulo Nias, off Sumatra, which is about 3,000 feet high, is described by Dr. Jack as being overspread by coral and large shells of the *Chama* (*Tridacna*) *gigas*, which rest on quartzose and arenaceous rocks, at various levels from the sea-coast to the summit of the highest hills.

The cliffs of the island of Timor in the Indian Ocean are composed, says Mr. Jukes, of a raised coral reef abounding in *Astræa*, *Mæandrina*, and *Porites*, with shells of *Strombus*, *Conus*, *Nerita*, *Arca*, *Pecten*, *Venus*, and *Lucina*. On a ledge about 150 feet above the sea, a Tridacna (or large clam shell), two feet across, was found bedded in the rock with closed valves, just as they are often seen in barrier reefs. This formation in the islands of Sandalwood, Sumbawa, Madura, and Java, where it is exposed in sea cliffs, was found to be from 200 to 300 feet thick, and it is believed to ascend to much greater heights in the interior. It has usually the form of a 'chalk-like' rock, white when broken, but in the weathered surface turning nearly black.†

It appears, therefore, premature to assert that there are no recent coral formations uplifted to great heights, for we are only beginning to be acquainted with the geological structure of the rocks of equatorial regions. Some of the upraised islands, such as Elizabeth and Queen Charlotte, in the Pacific, although placed in regions of atolls, are described by Captain Beechey and others as flat-topped, and exhibiting no traces of lagoons. In explanation of the fact, we may presume that, after they had been sinking for ages, the descending movement was relaxed; and while it was in the course of being converted into an ascending one, the ground remained for a long season almost stationary, in which case the corals within the lagoon would build up to the surface, and reach the level already attained by those on the margin

* Beechey's Voyage, vol. i. p. 45.

† Paper read to Brit. Assoc. Southampton, 1846. Dr. Duncan informs me that these coral cliffs are now known to belong to the Tertiary period.

of the reef. In this manner the lagoon would be effaced, and the island acquire a flat summit.

It may, however, be thought strange that many examples have not been noticed of fringing reefs uplifted above the level of the sea. Mr. Darwin, indeed, cites one instance where the reef preserved, on dry land in the Mauritius, its peculiar moat-like structure; but they ought, he says, to be of rare occurrence, for in the case of atolls or of barrier or fringing reefs, the characteristic outline must usually be destroyed by denudation as soon as a reef begins to rise; since it is immediately exposed to the action of the breakers, and the large and conspicuous corals on the outer rim of the atoll or barrier are the first to be destroyed and to fall upon the bottom of vertical and undermined cliffs. After slow and continued upheaval a wreck alone can remain of the original reef. If, therefore, says Mr. Darwin, 'at some period as far in futurity as the secondary rocks are in the past, the bed of the Pacific with its atolls and barrier reefs should be converted into a continent, we may conceive that scarcely any or none of the existing reefs would be preserved, but only widely spread strata of calcareous matter derived from their wear and tear.'*

When it is urged in support of the objection before stated (p. 612) that the theory of atolls by subsidence implies the accumulation of calcareous formations 2,000 or 3,000 feet thick, it must be conceded that this estimate of the minimum thickness of the deposits is by no means exaggerated. On the contrary, when we consider that the space over which atolls are scattered in Polynesia and the Indian oceans may be compared to the whole continent of Asia, we cannot but infer from analogy that the differences in level in so vast an area have amounted, antecedently to subsidence, to 5,000 or even a greater number of feet. Whatever was the difference in height between the loftiest and lowest of the original mountains or mountainous islands on which the different atolls are based, that difference must represent the thickness of coral which has now reduced all of them to one level. Flinders, therefore, by no means exaggerated the

* Letter to Mr. Maclaren, Scotsman, 1843.

volume of the limestone, which he conceived to have been the work of coral animals; he was merely mistaken as to the manner in which they were enabled to build reefs in an unfathomed ocean.

But is it reasonable to expect, after the waste caused by denudation, that calcareous masses, gradually upheaved in an open sea, should retain such vast dimensions? Or may not limestones of the cretaceous and oolitic epochs, which attain in the Alps and Pyrenees a thickness of 3,000 or 4,000 feet, and are in great part made up of coralline and shelly matter, present us with a true geological counterpart of the recent coral reefs of equatorial seas? I am also reminded by Dr. Duncan that the Miocene coral formations of Jamaica are enormously thick.

Before we attach serious importance to arguments founded on negative evidence, and opposed to a theory which so admirably explains a great variety of complicated phenomena, we ought to remember that the upheaval to the height of 4,000 feet of atolls in which the coralline limestone would be 4,000 feet thick, implies, first, a slow subsidence of 4,000 feet, and, secondly, an elevation of the same amount. Even if the reverse or ascending movement began the instant the downward one ceased, we must allow a great lapse of ages for the accomplishment of the whole operation. We must also assume that at the commencement of the period in question the equatorial regions were as fitted as now for the support of reef-building zoophytes. This postulate would demand the continuance of a complicated variety of conditions throughout a much longer period than they are usually persistent in one place.

To show the difficulty of speculating on the permanence of the geographical and climatal circumstances requisite for the growth of reef-building corals, we have only to state the fact that there are no reefs in the Atlantic, off the west coast of Africa, nor among the islands of the Gulf of Guinea, nor at St. Helena, Ascension, the Cape Verds, or St. Paul's. With the exception of Bermuda, there is not a single coral reef in the central expanse of the Atlantic, although in some parts the waves, as at Ascension, are charged to excess with cal-

careous matter. The capricious distribution of coral reefs is probably owing to the absence of fit stations for the reef-building polypifers, other organic beings in those regions obtaining in the great struggle for existence a mastery over them. Their absence, in whatever manner it be accounted for, should put us on our guard against expecting upraised reefs at all former geological epochs, similar to those now in progress.

Lime, whence derived.—Dr. Macculloch, in his System of Geology, vol. i. p. 219, expressed himself in favour of the theory of some of the earlier geologists, that all limestones have originated in organised substances. If we examine, he says, the quantity of limestone in the primary strata, it will be found to bear a much smaller proportion to the siliceous and argillaceous rocks than in the secondary; and this may have some connection with the rarity of testaceous animals in the ancient ocean. He further infers, that in consequence of the operations of animals, 'the quantity of calcareous earth deposited in the form of mud or stone is always increasing; and that as a secondary series far exceeds the primary in this respect, so a third series may hereafter arise from the depths of the sea, which may exceed the last in the proportion of its calcareous strata.'

The comparative scarcity of carbonate of lime in the oldest rocks insisted upon in the passage here cited, was chiefly deduced from observations on the geology of Scotland, with which Dr. Macculloch was familiar. Of late years our Canadian surveyors have taught us that the most ancient series of rocks yet discovered in the earth's crust, the Laurentian, contain vast formations of limestone; and the theory of metamorphic action, by which the ancient fossiliferous rocks have been transformed into those of the crystalline series (see Vol. I. p. 138), puts us on our guard against expecting any exact correspondence in the quantity of particular minerals, such as lime, contained in the hypogene, as contrasted with the incumbent formations.

We observe that, in volcanic countries, there is an enormous evolution of carbonic acid, either free, in a gaseous form, or mixed with water; and the springs of such dis-

tricts are usually impregnated with carbonate of lime in great abundance. No one who has travelled in Tuscany, through the region of extinct volcanos and its confines, or who has seen the map constructed by Targioni (1827), to show the principal sites of mineral springs, can doubt, for a moment, that if this territory was submerged beneath the sea, it might supply materials for the most extensive coral reefs. The importance of these springs is not to be estimated by the magnitude of the rocks which they have thrown down on the slanting sides of hills, although of these alone large cities might be built, nor by a coating of travertin that covers the soil in some districts for miles in length. The greater part of the calcareous matter passes down in a state of solution to the sea, and in all countries the rivers which flow from chalk and other marly and calcareous rocks carry down vast quantities of lime into the ocean. Lime is also one of the component parts of augite and other volcanic and hypogene minerals, and when these decompose it is set free, and may then find its way in a state of solution to the sea.

The lime, therefore, contained generally in sea-water, and secreted so plentifully by the testacea and corals of the Pacific, may have been derived either from springs rising up in the bed of the ocean, or from rivers fed by calcareous springs, or impregnated with lime derived from disintegrated rocks, both volcanic and hypogene. If this be admitted, the greater proportion of limestone in the more modern formations as compared to the most ancient, will be explained, for springs in general hold comparatively a small quantity of siliceous and still less of aluminous matter in solution, but they are continually subtracting calcareous matter from the inferior rocks. The constant transfer, therefore, of carbonate of lime from the lower or older portions of the earth's crust to the surface, must cause at all periods, and throughout an indefinite succession of geological epochs, a preponderance of calcareous matter in the newer as contrasted with the older formations.

CONCLUDING REMARKS.

In the concluding chapters of the First Book, I examined in detail a great variety of arguments which have been adduced to prove the distinctness of the state of the earth's crust at remote and recent epochs. Among other supposed proofs of this distinctness, the dearth of calcareous matter, in the ancient rocks above adverted to, might have been considered. But it would have been endless to attempt to reply to all the objections urged against those who would represent the course of nature at the earliest periods as resembling in all essential circumstances the state of things now established. We have seen that a strong desire has been manifested to discover in the ancient rocks the signs of an epoch when the planet was uninhabited, and when its surface was in a chaotic condition and uninhabitable. The opposite opinion, indeed, that the oldest of the rocks now visible may be the last monuments of an antecedent era in which living beings may already have peopled the land and water, has been declared to be equivalent to the assumption that there never was a beginning to the present order of things.

With equal justice might an astronomer be accused of asserting that the works of creation extended throughout *infinite* space, because he refuses to take for granted that the remotest stars now seen in the heavens are on the utmost verge of the material universe. Every improvement of the telescope has brought thousands of new worlds into view; and it would, therefore, be rash and unphilosophical to imagine that we already survey the whole extent of the vast scheme, or that it will ever be brought within the sphere of human observation.

But no argument can be drawn from such premises in favour of the infinity of the space that has been filled with worlds; and if the material universe has any limits, it then follows, that it must occupy a minute and infinitesimal point in infinite space.

So if, in tracing back the earth's history, we arrive at the

monuments of events which may have happened millions of ages before our times, and if we still find no decided evidence of a commencement, yet the arguments from analogy in support of the probability of a beginning remain unshaken; and if the past duration of the earth be finite, then the aggregate of geological epochs, however numerous, must constitute a mere moment of the past, a mere infinitesimal portion of eternity.

It has been argued, that, as the different states of the earth's surface, and the different species by which it has been inhabited, have all had their origin, and many of them their termination, so the entire series may have commenced at a certain period. It has also been urged, that, as we admit the creation of man to have occurred at a comparatively modern epoch—as we concede the astonishing fact of the first introduction of a moral and intellectual being—so also we may conceive the first creation of the planet itself.

I am far from denying the weight of this reasoning from analogy; but although it may strengthen our conviction, that the present system of change has not gone on from eternity, it cannot warrant us in presuming that we shall be permitted to behold the signs of the earth's origin, or the evidences of the first introduction into it of organic beings. We aspire in vain to assign limits to the works of creation in *space*, whether we examine the starry heavens, or that world of minute animalcules which is revealed to us by the microscope. We are prepared, therefore, to find that in *time* also the confines of the universe lie beyond the reach of mortal ken. But in whatever direction we pursue our researches, whether in time or space, we discover everywhere the clear proofs of a Creative Intelligence, and of his foresight, wisdom, and power.

As geologists, we learn that it is not only the present condition of the globe which is suited to the accommodation of myriads of living creatures, but that many former states also were adapted to the organisation and habits of prior races of beings. The disposition of the seas, continents and islands, and the climates, have varied; the species likewise have been changed; and yet they have all been

so modelled, on types analogous to those of existing plants and animals, as to indicate, throughout, a perfect harmony of design and unity of purpose. To assume that the evidence of the beginning or end of so vast a scheme lies within the reach of our philosophical enquiries, or even of our speculations, appears to be inconsistent with a just estimate of the relations which subsist between the finite powers of man and the attributes of an Infinite and Eternal Being.

GENERAL INDEX.

THE END.

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